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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1955 THANKSGIVING MEETING

AT

THE UNIVERSITY OF CHICAGO

November 25 and 26, 1955

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AMERICAN PHYSICAL SOCIETY

1955 THANKSGIVING MEETING AT CHICAGO, NOVEMBER 25–26, 1955

THE **1955 Thanksgiving meeting of the American Physical Society** will be held at Chicago on **Friday and Saturday, November 25 and 26.** It is always a pleasure to announce that we shall conform to the old and good traditions of this meeting. The host institution will be the University of Chicago. The headquarters of the meeting will be in Room 480 of the Research Institutes Building, 5630 Ellis Avenue. Room 209 of Eckhart Laboratory will be available for social gatherings on Friday up to 4 P.M. and on Saturday throughout the day. The scientific sessions will be distributed over various buildings of the campus. The administrator of the meeting will be Mrs. Dorothy C. Johnson, whose experience and skill in the art have served us well heretofore and have already earned her many thanks on which many more will follow.

Hotel. The Hotels Windermere (1642 East 56 Street, Chicago 37, Illinois) will as heretofore assume the responsibility of lodging our members in its own rooms, until these are booked to capacity, and thereafter in neighboring hotels. For the benefit of those who have not yet attended a Chicago meeting: this hotel is about 15 minutes' walk from the University, and taxis are available. Those who come by train from the East (Pennsylvania or New York Central railroads) should get off at Englewood and take a taxi; those who come by train from St. Louis may take the Illinois Central and get off at Woodlawn; those who come by train from other directions go to the terminal stations and may go to Michigan Boulevard at Van Buren Street to use the Illinois Central suburban service to go to 57th Street.

The **registration desk** will be located in Room 480 of the Research Institutes Building, at 5630 Ellis Avenue. A registration fee of one dollar will be solicited. Blackboards near the desk will carry notices of messages and information about the post-deadline sessions.

Invited papers will be given by L. W. Alvarez, S. Chandrasekhar, G. Dresselhaus, E. W. Friesen, G. Goldhaber, F. Low, D. E. Nagle, R. G. Newton, D. C. Peaslee, F. Rohrlich, C. C. J. Roothaan, M. Ross, J. A. Simpson, R. M. Steffen, and L. C. Teng. Other than the three from the University of California (Berkeley), they are drawn from Illinois and contiguous states. Those of Chandrasekhar and Simpson will embody the observations and conclusions of the authors from the distinguished international Congress on Cosmic Rays recently held in Mexico; those of Alvarez and Nagle will pertain to observations made with that remarkable new instrument, the bubble-chamber.

One hundred and eighty-three contributed papers are distributed among eighteen sessions. This is not much more than last year's total (168), a fact which when combined with similar facts about other 1955 meetings suggests a welcome stabilization of the size of our conventions; this inference may be frustrated by the future, as have such inferences about *The Physical Review*. It is evident that reactions of transmutation and semiconductor physics are still booming.

The **banquet of the Society** will be held in the Quadrangle Club, 1155 East 57 Street at the southeast corner of University Avenue, at seven o'clock on Friday evening. The price will be $3.50, including tips. Use of the reservation form on the inside back-cover page is advised, or alternatively, purchase of tickets as soon as you register on Friday morning. (This is one of the meetings at which the banquet must perforce be held on the first evening, allowing thus almost no time for indecision.) The after-dinner speakers will be announced on the bulletin board near the registration desk if not in this Bulletin.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special impor-

tance, will be considered for admission to a special supplementary programme if the abstracts are received before Saturday, November 19, at the office of the Society. Mark these abstracts clearly for the Chicago post-deadline programme, lest they get mixed up with the abstracts for the Annual Meeting of which the deadline is the same. The titles of such papers as may be accepted will be written on the bulletin board, and the papers will be given at the end of Session H.

The **Council** of the American Physical Society will meet at 11 A.M. on Friday in Room 180 of the Research Institutes Building (5630 Ellis Avenue) unless contrary notice is distributed to its members.

Read the **preliminary announcement of the 1956 Annual Meeting** which follows immediately. Other subsequent meetings and their deadlines are announced on page 7 of this Bulletin, as also the rules for preparation of abstracts (pay heed to the new rule imposing a special and expensive condition on the withdrawal of abstracts that have already gone to press).

Titles and abstracts of papers contributed to this meeting are printed hereinafter, and in exactly this form they will reappear in a future issue of *The Physical Review*. Errata will be printed on an adjacent page of that issue if mailed ***immediately on the receipt of this Bulletin*** to Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. The reason we say "immediately" is that it is desired to republish these abstracts in the *Review* before the end of 1955. Do not send in the abstract marked with corrections! Write out the corrections in the form "instead of . . . read . . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Preliminary Announcement of the 1956 Annual Meeting

The 1956 Annual Meeting of the American Physical Society will be scheduled in a markedly different way from all that have gone before. True, it will be in New York as is the custom, and the sessions will be in midtown hotels and in the Manhattan Center as they were in 1955. In 1956, however, our meeting will be a part of the twenty-fifth anniversary celebration of the American Institute of Physics. Our first three days of scientific sessions will be Monday, Tuesday, and Wednesday, January 30–31 and February first. The banquet will be held on Wednesday evening. On Thursday morning we shall have the traditional joint ceremonial session of our Society and the American Association of Physics Teachers, comprising the Retiring Presidential Address of R. T. Birge, the Richtmyer lecture, and the Oersted Medal presentation. Thursday afternoon is set aside for the addresses to be delivered in honor of the Institute before all of the Founder Societies together assembled. On Friday, February third, we resume our scientific sessions. Extension of our meeting into Saturday is conceivable if the influx of contributed papers should be abnormally great, which we hope it will not be.

Deadline for receipt of abstracts at the office of the Society (American Physical Society, Columbia University, New York 27, New York) **is Friday November eighteenth.**

HOTEL INFORMATION

January 30–February 4, 1956

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. John Grundhofer, Front Office Manager of the New Yorker, in the manner directed below. Overflow will be accommodated at the Statler. The New Yorker will forward late reservations to the Statler for confirmation to you. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested the hotels will hold reservations only to 6 P.M. of the day of your arrival. Check out time is 3 P.M.

HOTEL RATES

HOTELS	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	One Room for 3 persons with bath per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$7.00–$ 9.00	$ 9.00–$12.00	$10.50–$16.00	$12.00–$15.00	$25.00 and up
Statler 7th Avenue at 33rd Street	$8.00–$10.00	$10.00–$14.00	$11.00–$18.00	$13.00–$18.00	$30.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off

Tear Off

To: FRONT OFFICE MANAGER
HOTEL NEW YORKER
34TH STREET AND 8TH AVENUE
NEW YORK, NEW YORK

A.I.P.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1956 A.I.P. Convention. I / We plan to arrive ..... and remain until .....

Print below Persons in Your Party

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1955–1956

Place	*Meeting dates*	*Deadline date*
Chicago	November 25–26	past
Los Angeles*	December 28–30	past
New York	January 30–February 3	November 18
Houston	February 24–25	December 30
Pittsburgh	March 15–17	January 13
Washington	April 26–28	February 17
New Haven	June 21–23	April 27
Eugene*	June 21–23	not decided

* Abstracts for the Los Angeles and Eugene meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

EPITOME OF THE 1955 CHICAGO MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are those of halls).

Friday Morning

A. Radioactive nuclei. Eckhart.

B. Apparatus and techniques, I. Mandel.

C. Theoretical physics, I. Cobb.

D. Magnetism; magnetic resonance. Kent.

E. General nuclear physics. Oriental.

Friday Afternoon

G. Apparatus and techniques, II; Teng, Friesen. Oriental.

H. Cosmic-ray Congress at Guanajuato: Simpson, Chandrasekhar; cosmic rays. Post-deadline papers, if any. Mandel.

I. Neutron scattering and absorption; photoneutron reactions. Eckhart.

K. Theoretical physics, II; Low, Ross, Peaslee, Newton. Cobb.

N. Dresselhaus; semiconductors, I. Kent.

Friday Evening

Banquet of the American Physical Society. Quadrangle Club.

Saturday Morning

P. Reactions of transmutation and nuclear energy levels, I. Oriental.

Q. Alvarez, Nagle; mesons. Mandel.

R. General solid-state physics. Eckhart.

S. Rohrlich, Roothaan, Steffen. Cobb.

T. Semiconductors, II. Kent.

Saturday Evening

U. Semiconductors, III. Kent.

V. Goldhaber; heavy mesons and hyperons. Mandel.

W. Reactions of transmutation, II; Coulomb excitation, fission. Eckhart.

X. General physics. Cobb.

Y. The Brookhaven electron analog. Oriental.

PROGRAMME

FRIDAY MORNING AT 10:00

Eckhart 133

(A. C. G. MITCHELL presiding)

Radioactive Nuclei

A1. Decay of Ca^{49} (8.4-min).* DAVID W. MARTIN, S. BRADLEY BURSON, AND JAMES M. CORK, *Argonne National Laboratory.*—The beta and gamma radiations of radioactive Ca^{49} have been studied with the Argonne 256-channel coincidence scintillation spectrometer. Sources were prepared by irradiation in the Argonne reactor (CP 5) of samples enriched to about 12% in Ca^{48}. Gamma rays of 3.24±0.05 and 4.30±0.05 Mev were observed to decay with the 8.4±0.1-minute period in the NaI (Tl) pulse-height distribution, in which a well collimated geometry was used. The 4.30-Mev gamma ray has an intensity of about 5% that of the 3.24-Mev transition. Calibration was based on the 4.45-Mev gamma ray of C^{12} excited by an (α,n) reaction in a shielded Po-Be source.[1] A beta ray with an end-point energy of 1.93±0.10 Mev is found to be in coincidence with the 3.24-Mev gamma ray from a coincidence absorption curve. A softer beta ray in the neighborhood of 1 Mev is in coincidence with the 4.30-Mev gamma ray. The indicated decay energy of 5.1±0.2 Mev is consistent with the beta decay systematics of this region of the nuclide chart.[2]

* Work performed under auspices of U. S. Atomic Energy Commission.
[1] R. J. Breen and M. R. Hertz, Phys. Rev. **98**, 599 (1955).
[2] K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).

A2. Scandium-50. H. MORINAGA AND E. BLEULER, *Purdue University.*—In order to look for Sc^{50} which can be produced by an (n,p) reaction on Ti^{50}, titanium metal and TiO_2 were bombarded with Be-*d* neutrons from the cyclotron. The gamma-ray spectrum showed a line at 1.56 Mev which decayed with a half-life of 1.5 min. Also, beta rays with a maximum energy of about 3.5 Mev and the same half-life were detected. The intensities of the beta and gamma rays are about the same. No other radiations with a half-life between several seconds and several days were found, except for those from known isotopes expected to be produced by neutron bombardment of the samples used. This 1.5-min activity is thus assigned to Sc^{50} since no possible impurities can produce such an activity and because the energy of the gamma ray coincides well with the energy of the first excited state of Ti^{50}. Since no other gamma ray of 1.5-min half-life was found, the decay must proceed to the 2^+ first excited state ($\log ft = 5$) indicating that the spin of Sc^{50} is most likely to be 2^+. This would be an example of the violation of Nordheim's rule.

A3. Radiations from Mo^{91}.* NORWOOD GOVE, FRED A. SMITH, AND R. A. BECKER, *University of Illinois.*—A detailed study has been made of the disintegration scheme of Mo^{91} (produced by a gamma-*n* reaction with the 22-Mev betatron) during the past year. Gamma-radiation energies were measured at 1540±20, 1210±30, and 658±3 kev, all of which are associated with the 65.5-second activity. Three positron groups were found to be involved in the above activity and a single group was found to be associated with the 15.5-min decay. Coincidences were detected between positrons, and the first two gamma rays listed in the foregoing. The third gamma ray is not involved in coincidences. A tentative decay scheme will be discussed.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

A4. Disintegration of Te^{129}. WILLIAM E. GRAVES AND ALLAN C. G. MITCHELL, *Indiana University.**—The disintegration of Te^{129} has been investigated with the help of a magnetic lens spectrometer, permanent field spectrometer with photographic recording, and scintillation counters. The half-lives of the isomeric states in the parent were found to be 41 days and 74 minutes, respectively. The 74 minute state decays to I^{129} with the emission of beta-ray groups whose end-point energies and relative abundances are 1.453 Mev (71%), 0.989 Mev (15%), 0.69 Mev (4%), and 0.29 Mev (10%). Gamma rays of 0.027, 0.212, 0.475, 0.725, and 1.12 Mev were found. The 41 day state decays, for the most part, to the 74 minute state of Te^{129} with the emission of a highly internally converted gamma ray of energy 106.3±0.1 kev for which the K/L ratio is unity. A beta-ray transition, of low intensity, from the 41 day state of Te^{129} to the ground state of the product is postulated. Gamma-gamma and beta-gamma coincidence experiments using scintillation spectrometers served to indicate the probable level shceme of I^{129}. A discussion of the disintegration scheme will be given suggesting probable spins and parities of the levels.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

A5. Decay of 72 Second and 49 Day In^{114}.* LEE GRODZINS AND HENRY MOTZ, *Brookhaven National Laboratory.*—Scintillation counter coincidence experiments were performed on the 72 sec activity produced by p,n and $d,2n$ cyclotron bombardments of enriched Cd^{114} and the 49 day In^{114} produced by neutron capture of enriched In^{113}. By comparing the K x-ray, 722 coincidences per x-ray for 72 sec and 49 day In^{114}, the ground state K branch to the 1278 state in Cd^{114} was found to be $\leqslant 0.2\%$ confirming the assignment of $4+$.[1] Using 49 day In^{114} the previously reported 1300–556 coincidences[2] were not confirmed, the upper limit being 0.1% of the 722–556 coincidences. The gamma ray of ~1300 kev was found to be in coincidence with a 700 kev beta spectrum with a branching ratio of 0.09%. The log ft value of 5.73 is consistent with a $2+$ assignment for the 1300 kev level in Sn^{114}, in agreement with the systematics of even-even nuclei. A 3.5% K-branch was found from the 72 sec In^{114}, presumably to the ground state of Cd^{114}.

* Work performed under contract with the U. S. Atomic Energy Commission.
[1] N. Brazos and R. Steffen, Phys. Rev. **99**, 1645(A) (1955).
[2] Johns, McMullen, Donnelly, and Nable, Can. J. Phys. **31**, 225 (1953)

A6. Decay of Cs^{138}.* R. B. DUFFIELD,† M. E. BUNKER, J. P. MIZE, AND J. W. STARNER, *Los Alamos Scientific Laboratory.*—The decay of the fission product Cs^{138} (32.0 min) has been studied with beta- and gamma-scintillation spectrometers and a 141-gauss, 180° permanent magnet spectrograph. As observed previously,[1] there is no detectable ground-state beta transition. Twelve gamma rays were found with energies of 0.1389, 0.1931, 0.2289, 0.4106, 0.4626, 0.5495, 0.87, 1.010, 1.426, 2.21, 2.63, and 3.34 Mev. The intensities of the gamma rays relative to the total number of disintegrations were found to be 2, 1, 2, 3, 26, 8, 4, 25, 73, 18, 9, and 0.5%, respectively. Internal conversion measurements indicate that

the multipolarity of the 0.1389-Mev transition is predominantly $M1$. On the basis of the above data and the results of a number of gamma-gamma and beta-gamma coincidence studies, a consistent decay scheme is proposed which involves levels in Ba^{130} at 1.426, 1.89, 2.21, 2.30, 2.44, 2.63, and 3.34 Mev. The angular correlation of the 1.010 Mev—1.426 Mev cascade has been measured. The experimental results are in best agreement with a $0(Q)2(D)3$ correlation. The spin and parity assignment for the ground state of Cs^{130} which is most consistent with the established features of the decay scheme is 3−.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Department of Physics, University of Illinois, Urbana, Illinois.
[1] Langer, Duffield, and Stanley, Phys. Rev. **89**, 907 (1953).

A7. Nuclear Levels in Tm^{169}, Lu^{175}, and Lu^{177} as Derived from the Radioactive Isotopes of Yb. J. M. Cork, M. K. Brice, D. W. Martin, L. C. Schmid, and R. G. Helmer, *University of Michigan.*—Using Yb of high purity (99.8%) irradiated in the maximum flux of the Argonne pile and studied by scintillation and magnetic photographic spectrometers, a re-evaluation of the energies of the radiations has been made. Several previously unreported gamma rays are found and nuclear level schemes for Tm^{169}, Lu^{175}, and Lu^{177} proposed. Several of the levels appear to be rotational states in the unified nuclear model. Yb^{169} decays with a half-life of 30.6 days by K capture, followed by eleven gamma rays in Tm^{169}. Rotational levels lie at 8.4, 118.3, and 139.1 kev. The gamma energies are 8.4, 20.6, 63.2, 93.6, 109.9, 118.3, 130.7, 177.7, 198.6, 261.0, and 308.3 kev. Yb^{175} decays with a half-life of 4.2 days by beta emission (474 kev max) followed by five gamma rays in Lu^{175}. Rotational levels exist at 114.1 and 251.9 kev. The gamma energies are 114.1, 137.8, 145.0, 282.9, and 397.0 kev. Yb^{177} decays with a half-life of 1.88 hours by beta emission followed by gamma transitions in Lu^{177}. In addition to any lower energy gamma rays, two high energy transitions are found at 1.080 and 1.228 Mev. The latter is a cross-over for the 1.080- and 0.148-Mev gammas which are in coincidence. The expected well-known daughter product Lu^{177}, if present at all, is too weak to be observed by the magnetic spectrometers, which suggests some possible error in the assignment of masses in the stable isotopes.

A8. Electron Capture Decay of Os^{185} and the Excited States of Re^{185}.* Charles H. Pruett and Roger G. Wilkinson, *Indiana University.*—The 95 day orbital electron capture decay of Os^{185} has been studied using magnetic beta-ray spectrometers and scintillation spectrometer techniques. The measurements disclosed the presence of gamma rays at 72.5 and 125 kev which have not been previously reported. With the information obtained from coincidence and intensity measurements it is possible to include these two gamma transitions in a decay scheme with the previously reported 875, 647, 234, and 162 kev transitions. Use was made of internal conversion coefficients, K/L ratios, and lifetimes of transitions to determine the multipolarities of the gamma rays. These determinations permit assignment of spins and parities to the various excited levels of Re^{185}. Levels at 125, 647, 809, and 875 kev are given the assignments of $g_{7/2}$, 1/2+, 1/2+, and 3/2+, respectively. The 125 kev level is interpreted as the first rotational level in Re^{185}. Arguments based on the relative intensities of capture to the excited levels and ground state of Re^{185} indicate an assignment of $p_{1/2}$ to the ground state of Os^{185}.

* Supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

A9. Energy Determination of Au^{198} Conversion Electrons.* D. R. Connors, W. C. Miller, and B. Waldman, *University of Notre Dame.*—The same 90° cylindrical electrostatic analyzer which was used to measure the photothresholds of Be and D[1] and the conversion lines of Cs^{137} [2] has been used to measure the conversion lines of Au^{198}. An absolute energy measurement, with an accuracy of 0.1%, can be made with this analyzer. A 1 mg/cm² layer of gold was evaporated onto a thin aluminum foil and was irradiated in the Argonne reactor. In the observed spectrum the K, L_I, L_{II}, L_{III}, M, and N lines were resolved. The K line had an intensity of ten times the beta background. The transition energy is found to be 411.8±0.3 kev in excellent agreement with the value of Muller, Hoyt, Klein, and Dumond.[3] The L_I:L_{II}:L_{III} intensity ratios are found to be in good agreement with the theoretical values of Rose and Goertzel.[4]

* Supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Noyes, Van Hoomissen, Miller, and Waldman, Phys. Rev. **95**, 396 (1954).
[2] Bhattacherjee, Waldman, and Miller, Phys. Rev. **95**, 404 (1954).
[3] Miller, Hoyt, Klein, and Dumond, Phys. Rev. **88**, 775 (1952).
[4] K. Siegbahn, *Beta and Gamma Ray Spectroscopy* (Interscience Publishers, Inc., New York, 1955), p. 905.

A10. Directional and Polarization-Direction Correlations in Pb 208 γ-γ Cascades.* G. T. Wood† and P. S. Jastram,‡ *Washington University.*—Direction-direction correlations and polarization-direction correlations have been measured for γ-γ cascades in Pb-208 following the decay of ThB. Together with previously measured internal conversion coefficients,[1,2] the present results yield spin and parity assignments of 3⁻, 5⁻, 4⁻, and 5⁻, respectively, to the 2.62, 3.20, 3.48, and 3.71 Mev levels in Pb-208, and multipolarity character assignments of $E3$, $E2$, $M1+E2$ ($\delta=-0.20\pm0.05$), and $M1+E2$ ($\delta=-0.028\pm0.010$), for the 2.62, 0.58, 0.51, and 0.86 Mev gamma rays, where δ is the ratio of the reduced quadrupole to dipole nuclear matrix elements. Assignments are based on angular correlation measurements between the 2.62–0.58 Mev, 0.58–0.51 Mev, and 2.62–0.86 Mev γ-γ cascades and on polarization distributions of the 2.62, 0.86, 0.51, and 0.51+0.58 Mev gammas. With the exception of the mixing ratio for the 0.51 Mev gamma our results are in agreement with the decay scheme previously proposed.[2]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† University Fellow in Physics.
‡ Now at Ohio State University.
[1] D. G. E. Martin and H. O. W. Richardson, Proc. Roy. Soc. (London) **A195**, 287 (1948).
[2] Elliott, Graham, Walker, and Wolfson, Phys. Rev. **93**, 356 (1954).

A11. Alpha Decay of Np^{237}. L. B. Magnusson, D. W. Engelkemeir, M. S. Freedman, F. T. Porter, and F. Wagner, Jr., *Argonne National Laboratory.*—Nine alpha groups from the decay of Np^{237} have been detected by ion pulse analysis[1]: 4.872 Mev (3.1%), 4.816 (3.5), 4.787 (53), 4.767 (29), 4.713 (1.7), 4.674 (3.3), 4.644 (6.0), 4.589 (0.5), 4.52 (0.02). Alpha standards were Th^{230} (4.682 Mev) and Po^{210} (4.877 Mev). Using scintillation, proportional and magnetic spectrometers, we observed transitions (kev, *photons/disintegration*, e^-): (20, *0*, *L*?, *M*?) (29, *0.14*, L_{13}, L_3, *M*), (56.8, *0*, L_2, L_3, *M*), (86.9, *0.14*, L_{13}, L_2, *M*, *N*), (145, *0.008*, *K*, *L*), (175, *0.001*, *K*), (200, *0.003*, *K*, *L*); also the Pa x-rays at (13, *0.9*), (16, *0.4*) and (92, *0.05*). Transition assignments were derived from α-e^-, α-γ, and γ-γ coincidences. The 4.872 alpha-particle emission leads to the Pa^{233} ground state. The 86 kev and most of the 30 kev transitions depopulate the second excited state (3.7×10^{-8} sec).[2] A fraction (which is "prompt") of the 30 kev, the 145, and complex (unresolved) 200 kev radiation arise from levels above 160 kev. This work was sponsored by the U. S. Atomic Energy Commission.

[1] D. W. Engelkemeir and L. B. Magnusson, Rev. Sci. Instr. **26**, 295 (1955).
[2] D. W. Engelkemeir and L. B. Magnusson, Phys. Rev. **94**, 1395 (1954).

A12. Energy Levels of Pu^{239} Populated by the Beta Decay of Np^{239}. J. M. HOLLANDER AND W. G. SMITH, *University of California,* AND J. W. MIHELICH, *Notre Dame University.*—The conversion-electron spectrum observed from the beta decay of 2.33-day Np^{239} to Pu^{239} has been studied with three 180° permanent-magnet photographic spectrographs. The Np^{239} was prepared by irradiation of U^{238} in the Livermore reactor followed by chemical separation of the neptunium. The following transitions, with multipolarities where known, were observed: 0.04464 ($M1+E2$), 0.04940 ($M1+E2$), 0.05725 ($E2$), 0.0614 ($E1$), 0.06782 ($E2$), 0.09832, 0.1033, 0.10610 ($E1$), 0.1064, 0.1253, 0.1818, 0.2099 ($M1$), 0.2264, 0.2264, 0.2284 ($M1$), 0.2546, 0.2731, 0.2777 ($M1$), 0.2856, 0.3161, and 0.3345 Mev. The energy-level scheme of Asaro, Thompson, and Perlman[1] has been found to describe some of the features of the decay but the observation of certain transitions requires the postulation of additional energy levels. An energy-level scheme based on transition energy sums and relative internal conversions will be presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Asaro, Thompson, and Perlman, Phys. Rev. **92**, 694 (1953).

A13. Gamma-Ray Induced Isomers with Half-Lives between 10^{-5} and 10^{-1} Second.* STANLEY H. VEGORS, JR., AND PETER AXEL, *University of Illinois.*—A technique was developed for the detection of radioactivity between the x-ray yield pulses of the University of Illinois 22 Mev betatron, and was applied to the measurement of radioactivities in the half-life range between 10^{-5} and 10^{-1} second. The validity of this approach was investigated by observing the known isomeric transitions in this range of half-lives in Pb^{206m}, Zn^{67m}, Ta^{181m}, and Y^{88m}. A search was undertaken to determine whether any undetected isomers exist in this range of half-lives. Twenty-two elements are investigated, and seven previously unreported activities were found. The elements, gamma-ray energies, and half-lives are as follows: As, 315 kev, approximately 14×10^{-5} sec; Mo, 98 kev, 16.5×10^{-5} sec; Pd, 160 and 300 kev, 33×10^{-5} sec; W, 370 kev, 16×10^{-5} sec; Tl, 410 kev and 720 kev, 65×10^{-5} sec; Tl, 520 kev, 5.3×10^{-4} sec; and Bi, 545 kev and 1.065 Mev, 2.7×10^{-3} sec. Negative results were obtained in a search for W^{180m} and Na^{23m} activities. The (γ,n) thresholds for the production of Pb^{206m}, Pb^{207m}, Y^{88m}, and the 16.5×10^{-5} sec. Mo activity is also measured.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 10:00

Mandel Hall

(D. W. KERST presiding)

Apparatus and Techniques, I

B1. Angular Momentum and Energy of the Ions in the Magneto-Ionic Isotope Separator. JOSEPH SLEPIAN, *Westinghouse Research Laboratories.*—In the magneto-ionic expander isotope separator,[1] the net current taken by the collectors is zero, and that by the impressed voltage bearing side walls is negligibly small. Hence, the total moment of momentum of the ions received by each collector is zero, and the total kinetic energy of the ions and electrons is the same at the collectors as it was at the input end. The increase in length of the discharge as it terminates upon the collectors, and the reduction in the temperature of the ions there, are both responsible for the high enrichment observed there, the deposit upon the collector adjacent to the negative wall being enriched in the lighter ion, and that upon the collector adjacent to the positive wall being enriched in the heavier ion. The method will offer isotopes of the metals more cheaply than any other method known to me.

[1] J. Slepian, Proc. Natl. Acad. Sci. 451–457 (July 15, 1955).

B2. Transmission Secondary Electron Multiplication for High Resolution Counting and Imaging. E. J. STERNGLASS AND M. M. WACHTEL, *Westinghouse Research Laboratories.*—Weak currents may be amplified with high space and time resolution using secondary electron multiplication through a series of plane-parallel insulating films, each covered with a thin layer of a heavy metal. The metallic layer serves to scatter the incident electrons so that they enter the insulator at large angles. The long secondary electron diffusion length in the insulator results in high yields and permits the use of relatively thick films, thereby keeping the number of fast transmitted electrons small. In order to allow reasonably low voltages between stages, the films must be very thin. The films used consist of a supporting film of SiO about 100 A thick, followed by ~20 A of Au and 400–600 A KCl. To obtain sufficient mechanical strength, they are carried by electro-formed screens of fine mesh and 50% open area. With this screen open area, a yield of 4 per stage was obtained at 2 to 3 kev. Less than 10% of the emerging electrons exceeded an energy of 6 ev, indicating that the homogeneity is adequate for high image and time resolution. Time response tests were carried out using the technique developed by R. V. Smith. A seven stage device with a 50Ω coaxial output and 0.75 inch diam screens spaced 0.20 inch apart gave a transit time of 3×10^{-9} sec and a rise time of $\lesssim1\times10^{-9}$ sec at 3 kv per stage.

B3. New Method for Determining the Range of Low-Energy Electrons in Solids. J. E. HOLLIDAY AND E. J. STERNGLASS, *Westinghouse Research Laboratories.*—The range of electrons at energies in the kilovolt region and below may be determined by measuring the number of backscattered electrons from composite layers as a function of the incident energy. This technique is especially useful at low energies, where the energy loss in supporting foils becomes appreciable. The material studied is deposited as a film on a thick base having greatly different backscattering properties. Using a monoenergetic electron beam, the fraction η of backscattered electrons is determined with a plane-parallel collector system that rejects the secondaries of <50 ev. For low primary energies, η is characteristic of the surface film. As the energy is increased, electrons penetrate to the base material. When the energy of the primaries is such that the range in the surface material is equal to twice its thickness, a marked change in η occurs. Using a series of aluminum layers of different thicknesses on a gold backing and observing the energy at which η begins to change, it was possible to obtain a range-energy curve for aluminum between 2 and 17 kev. The results are in good agreement with Bethe's theory of stoppping and the experimental results of Lane and Zaffarano who utilized the

onset of penetration through layers carried by thin organic foils.

B4. Bistable Solid State Opto-Electronic Devices. E. E. LOEBNER, *Sylvania Electric Products, Inc.*—The bistable operation of ac circuits containing optically coupled and impedance matched electroluminescent and photoconductive elements has been investigated as a function of amplitude and frequency of the applied voltage, circuit current, and bias illumination. It was found that a series circuit of an electroluminescent and a photoconductive cell will stabilize either at a low-current and nonemitting or at a high-current and light-emitting operating condition within a range of voltages, whose mean magnitude and spread decreases with increasing illuminance bias. Selection of the desired operating mode can occur by means of electrical or optical or combined input signals. The time needed for switching into the other stable condition varies from few milliseconds to several seconds and depends not only on the operation and the time constants of the cells, as well on the strength and duration of the signal pulses, but also on the accompanying electro-photoluminescent and infrared quenching effects. Several logic networks, capable of computer operations, were built using series and parallel arrangements of electroluminescent and photoconductive cells and selecting light channels between them.

B5. Evapor-Ion Pump Behavior with Noble Gases. IGOR ALEXEFF AND EDWARD C. PETERSON, *University of Wisconsin.**—With the Evapor-ion pump, as previously described, relatively high pumping speeds for chemically active gases are easily attained. For inert gases which must be ionized and driven into the walls, high speeds have been difficult to reach. During the past year, various arrangements of electric and magnetic fields have been tried in attempts to improve ionization efficiency. The most effective arrangement produced a pumping speed for argon of 250 liters/sec at 1 ampere of ionization current. A high transparency grid and an axial magnetic field were used. The Evapor-ion pump is an efficient leak detector because of the difference in pumping speeds for air and inert gases. Spraying a leak with helium, for example, causes a sudden marked pressure rise.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.

B6. Negative Hydrogen Ion Source. J. A. WEINMAN, J. R. CAMERON, AND R. G. HERB, *University of Wisconsin.**—Positive hydrogen ions from a magnetic ion source[1] are accelerated to an energy of 20 kev. The ions then pass through a capillary tube into the center of which hydrogen is introduced.[2] The negative ions emerging from this tube are accelerated by an additional 30 kv, while the emerging secondary electrons are electrostatically repelled. The negative ions are then focused by an electrostatic "saddle-field" lens,[3] and separated by a magnetic analyzer. Currents measured in a collector after passing through the magnetic analyzer can readily be maintained at 20 to 25 microamperes and the source has yielded a maximum of 30 microamperes of negative hydrogen ions. The beam at the collector cup is normally ¼ to ½ inch in diameter. A pressure of 10^{-5} to 10^{-4} mm Hg is maintained in the negative hydrogen ion source container by an Evapor-ion pump,[4] which gives pumping speeds of approximately 7000 liters per second.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] J. Kistemaker and H. L. Douwes Dekker, Physica XVI **3**, 198 (1950).
[2] A. C. Whittier, Can. J. Phys. **32**, 275 (1954).
[3] O. Klemperer, *Electron Optics* (Cambridge University Press, Cambridge, New York, 1953), p. 64.
[4] R. H. Davis and A. S. Divatia, Rev. Sci. Instr. **25**, 1193 (1954).

B7. Energy Resolution Obtainable with a 2 Mev H_3^+ Beam. D. F. HERRING, R. A. DOUGLAS, E. A. SILVERSTEIN, AND REN CHIBA, *University of Wisconsin.**—The energy resolution obtainable with a diatomic hydrogen ion beam is appreciably inferior to that available with the atomic ion beam. The ion beams were provided by an electrostatic generator and defined in energy by a 90° cylindrical electrostatic analyzer. The resolution was investigated by observing the very narrow 0.993 Mev (p,γ) resonance in Al^{27} first for 0.993-Mev protons and then for 1.986-Mev diatomic ions. The resolution for the atomic ions was measured to be 0.09%, while that of the diatomic beam was 0.25%. Preliminary calculations of the resolution for values for the internal energy of the H_3^+ system less than the dissociation energy (2.65 ev) indicate that the bulk of the effect can be attributed to doppler broadening resulting from the internal motion in the H_3^+ ion.

* Work supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

B8. Investigation of Boron Trimethyl Counters. G. A. FERGUSON, C. W. PETERS, AND F. E. JABLONSKI, *U. S. Naval Research Laboratory.*—The use of boron trimethyl, $B(CH_3)_3$, as a counting gas has been reported.[1] The nonelectronegative character of its decomposition products is desirable for extended counter life. We have prepared $B(CH_3)_3$ according to a procedure similar to that described by Brown[2] using BF_3 generated from the nonenriched complex $CaF_2 \cdot BF_3$. Impurities were removed by a method suggested by Dr. M. Taylor of Howard University. A sample of the purified gas was analyzed by infrared spectroscopy and bands were found at locations indicated for boron trimethyl.[3] A cylindrical brass-walled counter, one inch in diameter and six inches in length, having a 4.5 mil tungsten anode was filled with purified, nonenriched boron trimethyl to pressures in the range 5–30 cm Hg. The response of these proportional counters, in a flux of Po-Be neutrons moderated in paraffin, has been compared with the response of a similar filling of BF_3. Differential pulse-height spectra have been observed for the two fillings. The resolution is roughly 30% for a 30-cm Hg pressure.

[1] O. H. Hauser, Z. Naturforsch. **7a**, 781 (1952).
[2] H. C. Brown, J. Am. Chem. Soc. **67**, 374 (1945).
[3] J. Goubeau and H. Becher, Z. anorg. u. allgem. Chem. **268**, 1 (1952).

B9. Recoil-Coincidence Method for Producing Monoenergetic *d-d* Neutrons. W. FRANZEN,* *University of Rochester*, AND P. HUBER AND L. SCHELLENBERG, *University of Basel.*—A method has been developed for eliminating background neutrons from a *d-d* neutron source. For this purpose, neutrons emitted from a deuterium gas target are observed in coincidence with the He^3 recoils also produced in the reaction. The gas volume is confined by means of a 0.5 mg/cm² Ni foil, and the recoil counter consists of a layer of ZnS crystals on the face of a photomultiplier mounted behind a system of apertures at 90±3° to the direction of incidence of the deuterons. A cylinder of Scintillon plastic attached to a photomultiplier mounted on a movable frame is used as a neutron counter. The factors influencing the energy resolution of the system have been analyzed. For a gas pressure of 3.5 cm Hg, the geometry of the system is designed to achieve a neutron energy spread of less than 10 kev for a deuteron bombarding energy between 400 and 1000 kev. This device is now in use for the measurement of total neutron cross sections, and its operation will be described in detail.

* On leave 1954–1955 at the University of Basel, Switzerland.

B10. Characteristics of the New Argonne Fast Neutron Chopper.* L. M. BOLLINGER, R. E. COTÉ, AND J. M. LEBLANC, *Argonne National Laboratory.*—A fast neutron chopper having unique features has been completed and is operating at reactor CP-5. It consists of a rotor of a new design spun about

a vertical axis at 15 000 rpm by a direct coupled dc motor. The rotor is a 10-inch diameter monel cylinder with a uranium core of 3 inch diameter. Two sets of 7 slits perpendicular to the axis of rotation intersect at 90° in the core. All slits are cigar-shaped, being 0.025 inch wide at both ends and 0.055 inch in the middle. This shape produces neutron bursts which, for a given speed, are twice as narrow as those given by conventional fast chopper slit designs. At full speed the average burst width is 2 μsec, giving a resolution of about 0.04 μsec with a 60-meter flight path. The shape of the cut-off function may be varied over a wide range by adjustment of collimator positions. The large slit area of the present rotor is to give a high flux for partial cross section measurements. A second rotor under construction, giving narrower neutron bursts, is intended for transmission measurements.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† The drive system is similar to that of the Brookhaven chopper.

B11. Third-Order Aberration and Focusing with Sector-Shaped Magnetic Field.* D. F. DEMPSEY, W. C. MILLER, AND B. WALDMAN, *University of Notre Dame.*—Magnetic focusing computations have been carried out which extend the first-order results of Herzog[1] and the second-order results of Hintenberger[2] for magnets whose edges are in the shape of straight lines or arcs of circles. The general formula obtained evaluates the transverse aberration of order a^3 which occurs at the focus of second-order instruments. It contains as a factor a term which may be equated to zero to yield parameters which result in third-order focusing. These have been plotted as design curves which allow a choice of many third-order magnets.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Herzog, Z. Physik **89**, 447, 786 (1934).
[2] H. Hintenberger, Z. Naturforsch. **3a**, 125, 669 (1948); **6a**, 275 (1951); Rev. Sci. Instr. **20**, 748 (1949).

B12. Attenuation of 1-cm Microwaves by Abnormal dc Discharge in Helium.* Z. GELLER AND W. LOW,† *The Hebrew University.*—The attenuation of 1 cm microwave was measured as a function of the distance from the cathode of a cold cathode dc discharge. Measurements were made for various pressures and current densities in the abnormal discharge region. The attenuation reaches a maximum before the beginning of the negative glow, falling off to small values in the positive column. Electron densities calculated from the attenuation data agree roughly with those found by other methods. Near the beginning of the negative glow negative attenuation or amplification was observed in a very narrow layer in about the same region where Merrill and Webb[1] have observed oscillations. The amplification increases with current density. The calculated density at this region corresponds to that obtained if the plasma were to oscillate with the microwave frequency. A possible explanation is a coupling between the microwave field and the longitudinal plasma oscillations which makes the microwaves grow as they traverse the discharge tube.

* Assigned to a Friday session at the request of one of the authors.
† Present address: Institute for Nuclear Studies, University of Chicago.
[1] H. J. Merrill and H. W. Webb, Phys. Rev. **55**, 1191 (1939).

FRIDAY MORNING AT 10:00

Cobb 110

(D. C. PEASLEE presiding)

Theoretical Physics, I

C1. Self-Consistent Treatment of the Nuclear Independent Particle Model. G. E. TAUBER* AND T. Y. WU, *National Research Council.*—A general central nucleon-nucleon interaction $V(|\mathbf{r}_i-\mathbf{r}_j|)$ including all possible central interactions, such as Wigner, Bartlett, Majorana, and Heinsenberg, has been chosen to satisfy the saturation requirements and to be consistent with some of the properties of the two-nucleon system, but contains the strength V_0 as an adjustable parameter. The wave function of the nucleus is an antisymmetric combination of products of the single-nucleon wave function ψ_i. The ψ_i and V_0 are determined by the Ritz variational principle and the empirical value of the total binding energy of the nucleus. It is then possible to find the "central field" $V(\mathbf{r})$ for a nucleon in any shell, and to calculate its binding energy from the Hartree-Fock equations. Calculations have been carried out for the O^{16} nucleus. With the value of V_0 so obtained, the total binding energies of O^{15} and O^{17} and the binding energy of the "last" nucleon has been calculated. The result that the last neutron in O^{17} outside the closed shells is weakly bound compared with the nucleons in the closed shells in O^{16} is consistent with the usual basic ideas in the shell model.

* Present address: Department of Physics, Western Reserve University, Cleveland, Ohio.

C2. *L-S* Interaction in Nuclei. L. S. KISSLINGER,* *Indiana University.*—The spin-orbit interaction in nuclei is derived from the two-body nucleon-nucleon interaction. Firstly, a calculation is made using only the tensor interaction, which is known to be present in the nucleon-nucleon interaction. Using a nuclear surface which is currently accepted, this calculation gives an interaction which is not in disagreement with experiment. Secondly, a more general approach is taken, one which is more nearly in accord with the spirit of the "coherent" model of the nucleus[1]. In this case the general nonrelativistic nucleon-nucleon scattering operator is used, and from this it is shown that a splitting arises which is consistent with observations. The mixed density function for the nucleus is evaluated as part of the calculation.

* National Science Foundation Predoctoral Fellow.
[1] Brueckner, Levinson, and Mahmoud, Phys. Rev. **95**, 217 (1954); K. A. Brueckner, Phys. Rev. **97**, 1353 (1955); and other recent publications by Brueckner *et al.*

C3. Hole-Particle Relations and *j-j* Coupling. R. W. KING *Purdue University.*—Odd-odd spins and β decay matrix elements involving neutrons and protons in $l+\frac{1}{2}$ orbits show marked departures from hole-particle equivalence in the *j-j* coupling scheme. The less abundant data on $l-\frac{1}{2}$ shells reveal no such marked departures for either odd-odd spins or β decay transition probabilities. This behavior shows that the spin-orbit interaction does not lead to *j-j* coupling over the complete shell. It appears that mutual interactions large enough to prevent *j-j* coupling are achieved when only a few particles are present in a shell. As particles are added the mutual interactions become less specific, and the average

tendency to j-j coupling re-emerges. A good approximation to j-j coupling is reached near the closure of an $l+\frac{1}{2}$ shell. The $l-\frac{1}{2}$ shells are forced to be j-j coupled by the exclusion principle. This point of view leads to a consideration of β transition probabilities as a function of the percent of shell crossed with the satisfying result that the image transitions appear as limiting cases of a continuous trend. Implications for individual orbital forbiddenness in (d,p) reactions and β decay are also apparent.

C4. Proton-Proton Scattering at 1 Bev.* WILLIAM RARITA,‡ *Case Institute of Technology.*—By using the partial wave analysis reported at the last Washington meeting[1] and limiting the l value to 3 we obtain a good fit to the experimental elastic angular distribution of protons scattered by protons at 1 Bev. The elastic cross section σ_e can then be evaluated. $\sigma_e=22.3$ mb and the absorption cross section $\sigma_a=25.7$ mb. $\sigma_a/\sigma_e=1.15$. By making the more restrictive assumption that the phase shifts δ_l depend solely on l and not j we find that the δ_l can be determined in terms of a single parameter. Usually three parameters would be needed to express the phase shifts. But the inequality relation between the forward angle scattering and the total cross section is best fitted at the minimum and thus gives two additional conditions. An unusual result is that for all values of the remaining parameter the absorption in the S state is less than that in the D state contrary to the expectation of the ray approximation of the optical model. On the other hand, the P and F state phase shifts behave well according to such a model and give a reasonable radius of interaction.

* Supported by U. S. Atomic Energy Commission.
‡ On sabbatical leave from Brooklyn College.
[1] William Rarita, Phys. Rev. **99**, 630(A) (1955).

C5. Phase Shift Analysis of Nucleon-Nucleon Scattering at 150 Mev.* SHOROKU OHNUMA AND DAVID FELDMAN, *University of Rochester.*—A phase shift analysis of the unpolarized n-p and p-p scattering as well as the polarized p-p scattering data at 150 Mev has been carried out on the assumption that nuclear forces are charge independent and that only states with total angular momentum $J\leq 2$ contribute; $^3P_2-{}^3F_2$ and $^3S_1-{}^3D_1$ coupling have been neglected, however. The formulas used to estimate the Coulomb-nuclear interference in p-p scattering are essentially nonrelativistic (although they include a kinematic correction so as to give agreement with the Møller formula at small angles). Those nuclear phase shifts which are common to the p-p and n-p systems are not identical to one another because of the Coulomb interaction; the differences between these two kinds of phase shifts have been estimated, assuming only a range for the nucleon-nucleon force, and have been found to be small. Polarized n-p scattering cross sections have been calculated for the same energy using the sets of phase shifts thus obtained and they will be compared with the experimental data. The implications of the analysis for the nature of the nucleon-nucleon interaction will also be discussed.

* This research was supported, in part, by the U. S. Atomic Energy Commission.

C6. Multiple Photon Production from Electron Pair Annihilation. J. JOSEPH, *State University of Iowa.*—Gupta[1] estimated the cross section for N-photon production, assuming that the principal contributions come from very soft photons (infrared divergence) *and* small scattering angles. Gupta justified these assumptions by an independent estimate of three-photon production. He regarded the latter as more reliable. Specializing his general result to $N=3$ one finds a discrepancy of a factor $\frac{1}{3}$. We have estimated N-photon production assuming *only* the infrared limiting form,[2] introducing this approximation at an earlier stage of the calculation. Our results agree with Gupta's, giving $\sigma_N\simeq\sigma_0[2\alpha\pi^{-1}\ln(\gamma/\epsilon)\times\ln(2\gamma)]^{N-2}/(N-2)!$ where γm is the electron energy in the laboratory system and ϵm is the experimental energy resolution. Moreover, we applied the substitution law to the double Compton[3] process to obtain three-photon pair annihilation. This result *agrees* with the general formula, differing from Gupta's value by a factor $\frac{1}{3}$. We also estimated the next terms in the high-energy expansion for $N=3$: $4\alpha r_0^2\ln(2\gamma)[\ln(2\gamma)+1]/\gamma$.

[1] S. N. Gupta, Phys. Rev. **98**, 1502 (1955).
[2] J. M. Jauch and F. Rohrlich, Helv. Phys. Acta **27**, 613 (1954).
[3] F. Mandl and T. H. R. Skyrme, Proc. Roy. Soc. (London) **A215**, 497 (1952).

C7. Contribution of the Electron to Pair Production in Atomic Hydrogen. F. ROHRLICH AND J. JOSEPH, *State University of Iowa.*—The total cross section for pair production by γ rays on a free electron in the high energy limit is (in units of αr_0^2) $\sigma=(28/9)\ln(2\omega/m)-106/9$, which includes recoil and exchange effects. The constant term is the result of an exact integration of Votruba's[1] formulas, who estimated it to be $-(102\pm4)/9$. Extracting the electron recoil distribution from Votruba's work permits one to correct the screening calculations of Wheeler and Lamb.[2] They neglected the recoil energy and exchange and found for complete screening in atomic hydrogen $\sigma_{coh}=16.4$ and $\sigma_{incoh}=19.8$ for the coherent and incoherent total cross sections. We find that the recoil energy is indeed negligible, but that exchange modifies their results to $\sigma_{coh}=-(28/9)\ln2\alpha+(97\pm10)/27=16.8\pm0.4$ and $\sigma_{incoh}=-(28/9)\ln2\alpha+77/27=16.1$. Exchange gives a smaller electronic momentum transfer distribution and therefore decreases the incoherent cross section, but increases slightly the coherent cross section due to the (negative) interference term between nuclear and electronic momentum transfer.

[1] V. Votruba, Bull. intern. acad. tech. Sci. **49**, 19 (1948).
[2] J. A. Wheeler and W. E. Lamb, Phys. Rev. **55**, 858 (1939).

C8. High-Energy Photoneutron-Proton Pair Ejection from Nuclei.* ALLEN ODIAN,† BERNARD FELD, WILLIAM RANKIN, PETER STEIN, ALBERT WATTENBERG, AND ROY WEINSTEIN, *Massachusetts Institute of Technology.*—The high-energy photoproduction of neutron-proton pairs from nuclei has been compared to the photodisintegration of the deuteron for 260 Mev photons. The differential cross sections for the production of these pairs from lithium and oxygen was compared with that for the photodisintegration of the free deuteron at proton angles of 35°, 60°, 90°, and 135° in the center of mass of the deuteron. The relative angular distribution from lithium and oxygen to deuterium was found to be flat within the experimental error. This indicates that if the mechanism for the photodisintegration of the real and *quasi*-deuterons is the same, then the relative angular momentum of a neutron and proton in a *quasi*-deuteron is the same as that in a free deuteron. The process shows a cross section dependence of $\sigma_{quasi\text{-}deuteron}=CNZ\sigma/A$ free deuteron where C is between 2.5 and 4 indicating that the mechanisms for the two processes are the same.

* Supported in part by the U. S. Atomic Energy Commission Office of Naval Research.
† Now at the University of Illinois, Urbana, Illinois.

C9. Electric-Monopole Transitions in Atomic Nuclei. E. L. CHURCH* AND J. WENESER,† *Brookhaven National Laboratory.*‡—Low-energy electric-monopole, or $E0$ transitions, ($\Delta I=0$, *no*), proceed solely by internal conversion, with zero units of angular momentum transferred to the ejected electron. Gamma-ray emission of this multipole order is strictly forbidden, although $E0$ pair production is possible for transition energies $>2\ mc^2$. It is pointed out that (1) the electric-mono-

pole mode of de-excitation is available between any two equal-parity states of the same spin, zero or otherwise, (2) that in such cases, $E0$ internal conversion may compete favorably with the paralleling magnetic-dipole and electric-quadrupole radiative transitions in heavy nuclei, and (3) that monopole matrix elements, $\langle i|\Sigma r_p{}^2|f\rangle$, may be particularly useful in the study of nuclear structure. The relative and absolute conversion properties of electric-monopole transitions have been calculated relativistically, including the effects of the finite nuclear size and atomic screening. These results have been used to analyze the available experimental data on the $2^+\rightarrow 2^+$ transitions in Pt^{196} and Hg^{198}, and to determine upper limits for the monopole matrix elements. These limits appear appreciably smaller than the values deduced for the well-known monopole transitions of the $0^+\rightarrow 0^+$ type. The possible significance of these results is considered with reference to current nuclear models.

* On leave from Frankford Arsenal, Philadelphia, Pennsylvania.
† Now on leave at the University of Illinois, Urbana, Illinois.
‡ Work performed under the auspices of the U. S. Atomic Energy Commission.

C10. Strength Function of Nuclear Energy Levels. H. H. BARSCHALL AND S. E. DARDEN, *University of Wisconsin.**—Measurements of the strength function (ratio of average reduced neutron width to level spacing) for levels in the compound nucleus have been continued.[1] Deviations from exponential attenuation of neutrons at average energies between 60 and 225 kev were observed. For manganese, a large effect found at all energies provides evidence for the S-wave peak in the strength function predicted by the complex square well model.[2] For selenium and niobium, the strength function computed assuming only S-wave interactions increases rapidly with neutron energy suggesting appreciable interactions of P-wave neutrons. An analysis of the data taking into account the effect of P-waves yields for selenium and niobium a P-wave strength function in qualitative agreement with calculations based on the complex square well theory which predicts a P-wave maximum at low neutron energies for these elements.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] S. E. Darden, Phys. Rev. **90**, 748 (1955).
[2] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).

FRIDAY MORNING AT 10:00

Kent 106

(G. E. PAKE presiding)

Magnetism; Magnetic Resonance

D1. A Low Voltage Magnet and Regulated Power Supply.* R. C. MOBLEY, C. H. BLAKEWOOD,† AND D. C. RALPH, *Louisiana State University.*—An electrogmanet constructed for use as an ion buncher[1] and its associated power supply will be described. The magnet produces a field of 15 kilogauss across a gap of ½ inch over an area of 100 sq in. The power supply is capable of delivering controlled currents up to 150 amperes at 20 volts to two series connected strip wound magnet coils. The current control circuit consists of a high gain closed loop servo system using a self-balancing electronic amplifier and a two stage single magnetic amplifier to yield the magnet coil current. The high internal gain of the system and the excellent zero stability of the self-balancing amplifier limits excursions in current to ±0.01%. The design and operating characteristics of the control circuit will be discussed.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Yale University.
[1] R. C. Mobley, Phys. Rev. **88**, 360 (1952).

D2. Magnetic Properties of Murdochite, Cu_4PbO_6. PALMER L. EDWARDS, *Naval Ordnance Laboratory.*—The paramagnetic susceptibility of Cu^{++}, octahedrally surrounded[1] by O^{--}, as found in the mineral murdochite,[2] was determined from 77°K to 845°K. Above room temperature the Curie-Weiss law is satisfied with $\theta = -700° \pm 50°$K. Below room temperature the reciprocal susceptibility curve bends slightly toward the temperature axis. From the linear portion of the curve the effective magnetic moment per Cu^{++} ion was found to be $1.75 \pm 0.02 \mu_B$, which is very near the value for complete orbital quenching. The large negative θ indicates that murdochite may be antiferromagnetic, although no transition temperature was observed in the susceptibility curve. A molecular-field analysis showed that the possible arrangements of the magnetic ions below a transition temperature would be such that the ions are antiferromagnetically arranged on each of three sublattices.

[1] C. L. Christ and Joan R. Clark (to be published in *American Mineralogist*).
[2] Kindly loaned by C. L. Christ of the U. S. Geological Survey, Washington, D. C.

D3. New Magnetic Transition in Mn_3ZnC. B. N. BROCKHOUSE, *Chalk River Laboratory,* AND H. P. MYERS, *University of British Columbia.*—Alloys with the approximate compositon Mn_3ZnC are ferromagnetic but the saturation magnetization shows a maximum in the region of 230°K. X-ray studies have shown that below 231°K the normal cubic structure becomes tetragonal with a c/a ratio changing smoothly from 0.994 at 77°K to 1.000 at 231°K. Neutron diffraction studies have shown that a set of lines which can be indexed as 111, 311, and 331 lines of a unit cell of double the normal size appear below 231°K. These lines have an intensity which increases steadily with decreasing temperature and are ascribed to magnetic scattering. Above 231°K the 100 line (normal cell) has an intensity which can be accounted for by simple ferromagnetism of equivalent manganese atoms. Below 231°K the intensity of the 100 line is greater than can be accounted for on this basis. Above the normal Curie temperature (~400°K) the diffuse scattering suggests moments of about $1.5\mu_B$ per manganese atom, consistent with the saturation magnetization above 231°K. Mn_3ZnC therefore appears to be a normal ferromagnetic material above 231°K. At this temperature a second-order transition occurs, involving a complex ordering of the manganese ions. Possible magnetic structures will be discussed.

D4. Magnetic Superexchange Interaction.* DAVID A. KOTTWITZ, *University of Pennsylvania.*—A straightforward formulation of the theory of superexchange for the standard tri-

atomic model has been carried out. Explicit determinantal wave functions are employed in a routine configuration interaction calculation based on perturbation theory. Orthogonal atomic orbitals are assumed, but, following Slater, are considered as disposable parameters. Our program is threefold in purpose: (1) to set up a formalism generalizable to "degenerate superexchange" and other indirect magnetic interactions; (2) to include within the analysis the hitherto neglected direct exchange interaction between the excited magnetic cation and the excited anion; (3) to obtain a formalism which permits us to test the sensitivity of results to the choice of perturbing excited states. It is found that inclusion of the direct exchange interaction referred to above does not essentially alter the previously given expressions[1,2] for superexchange coupling. The simple intuitive significance of this result will be discussed. The choice of excited states suitable for the perturbation calculation will also be discussed.

* This work was supported by the Office of Naval Research.
[1] P. W. Anderson, Phys. Rev. **79**, 350 (1950).
[2] J. H. Van Vleck, J. phys. radium **12**, 262 (1951).

D5. Microwave Resonance Relations in Anisotropic Single Crystal Ferrites.* J. O. ARTMAN, *Lincoln Laboratory.*—The ferromagnetic resonance relations in magnetically anisotropic single crystal ferrites have been re-examined. The basic theory has been considered previously by Smit[1] and Zeiger.[2] Generalized nomograms are presented which relate the microwave resonance frequency to the magnetic field, anisotropy parameter K/M, and magnetization M. These curves are derived for both negative and positive anisotropy spherical specimens oriented so that both the static and microwave magnetic fields lie in a (110) crystal plane. Results are given for calculations made on the assumption that the specimen exists as a single magnetic domain. The nature of the gradual alignment of M to the static magnetic field H is discussed in detail. Simplified formulas are given for the "quasi-line up" region in which the angle between M and H becomes small. The occurrence of multiple domain structures below magnetic saturation is also considered. The domains are assumed to be lamellas of two varieties arranged alternately. Resonance relations are derived for both negative and positive anisotropy crystals when H is applied along a [110] direction. These results are compared with recent experiments.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with Massachusetts Institute of Technology.
[1] J. Smit and H. G. Beljers, Philips Research Repts. **10**, No. 2, 113–130 (April, 1955).
[2] H. J. Zeiger, Lincoln Laboratory (private communication).

D6. A Lagrangian Formulation of the Gyromagnetic Equation of the Magnetization Field. T. L. GILBERT, *Armour Research Foundation of Illinois Institute of Technology.*—The gyromagnetic equation, $d\mathbf{M}/dt=\gamma\mathbf{M}\times\mathfrak{H}$, for the motion of the magnetization field, $\mathbf{M}(\mathbf{r})$, in a ferromagnetic material can be derived from a variational principle, as first shown by Döring.[1] Here $\mathfrak{H}$ is the effective internal field, including the magnetic field and contributions from exchange, anisotropy, and magnetoelastic effects. Using this variational principle, the equations of motion can be recast into a Lagrangian form. This makes possible a consistent derivation of the equations of motion of the magnetization field and other fields to which it may be coupled (e.g., the displacement field of the lattice and the electromagnetic field). It also permits the introduction of viscous damping effects in a consistent manner using the Rayleigh dissipation function. It is shown that viscous damping of the magnetization field leads to an equation of motion which reduces to the Landau-Lifshitz equation only when the damping is small. It is also shown that this Lagrangian formalism permits the introduction of damping due to disaccommodation in a consistent and very general way.

[1] W. Döring, Z. Naturforsch. **3a**, 374 (1948).

D7. Anisotropic Paramagnetic Absorption Spectrum of Manganous Ion in Cubic Zinc Sulfide. LAWRENCE M. MATARRESE, *United States Naval Research Laboratory,* AND CHIHIRO KIKUCHI, *University of Michigan.*—We have investigated the paramagnetic absorption spectrum of manganous ion in a natural crystal of cubic zinc sulfide and have found the anisotropy to be unusually pronounced. The maximum width of a hfs group is 45 gauss with the densities of the components approximately in the ratio 8:5:9:5:8. This pattern of density distribution is to be expected when quartic terms in the crystalline electric field potential predominate. The spectra were obtained at fields in the vicinity of 8500 gauss and at a microwave frequency of approximately 24 000 mc/sec. The angular dependence was investigated by varying the direction of the magnetic field in the (100), (110), and (111) planes of the crystal. Experimental results indicate that the symmetry of the crystalline electric field about the manganous ion is cubic. The cubic anisotropy constant, A, is -1.37, the sign being determined from the dependence of the hfs pattern upon the nuclear magnetic quantum number. The relationships among the anisotropy constant, the hfs coupling constant, and anion coordination will be discussed for several compounds.

D8. The Doublet Structure in Paramagnetic Absorption Spectra of Mn^{++} in Calcite.* CHIHIRO KIKUCHI, *Engineering Research Institute.*—Hurd, Sachs, and Hershberger[1] observed that some of the paramagnetic absorption lines of Mn^{++} in calcite are split into doublets for certain orientations of the magnetic field with respect to the crystal trigonal axis. According to their observations, the doublet separation is maximum near 60° and vanishes at 0° and 90°. The present paper suggests that this doublet splitting is due to the nonequivalent trigonal fields at the two calcium sites occupied by Mn^{++}. The present theory gives (1) $P_4^3(\cos\theta)$ for the angular dependence of the doublet splittings, (2) 23 gauss for the maximum splitting, (3) the ratio 5:4 for the splittings of the strong to weak doublets, and (4) isotropic absorption spectrum when the magnetic field varies in the equatorial plane. These results are in good agreement with experiment. The possible occurrence of the doublet splitting in other crystals will be discussed.

* This investigation was carried out under a contract with the Signal Corps. During the initial phases the author was associated with the Nucleonics Division, Naval Research Laboratory, Washington, D. C.
[1] Hurd, Sachs, and Hershberger, Phys. Rev. **93**, 373 (1954).

D9. Nuclear Magnetic Relaxation Times in Polyethylene.* I. J. LOWE, L. O. BOWEN, AND R. E. NORBERG, *Washington University.*—Direct measurements of T_1 and T_2 for the proton magnetic resonance in polyethylene have been made from observations of Bloch decays and spin echoes produced by microsecond pulses of 30 mc/sec radio-frequency power. Observations were made at temperatures between 240°K and 392°K using the same commercial stock material as Wilson and Pake.[1] The results are in substantial agreement with the relaxation times postulated by Wilson and Pake and show the coexistence of several very distinct T_2's between 260°K and 295°K. The T_2 values measured ranged from 4 microseconds near 240°K to 0.1 second in a molten sample at 392°K. Over much of this temperature range T_1 was measured to be of the order of 0.1 second with T_2 becoming nearly equal to T_1 at 392°K. The short T_2 component visible on the Bloch decays grows progressively weaker as the temperature is raised, becoming nearly undetectable by 340°K. Near 280°K there is a weak "slow-beat" structure on the Bloch decays.

* Supported by the Office of Naval Research and the U. S. Air Force through the O.S.R. of the Air Force Research and Development Command.
[1] C. W. Wilson and G. E. Pake, J. Polymer Sci. **10**, 503 (1953); C. W. Wilson, thesis (unpublished) Washington University, 1952.

FRIDAY MORNING AT 10:00

Oriental 104

(S. K. ALLISON presiding)

General Nuclear Physics

E1. Elastic Scattering of Protons from Na^{23}.* N. P. BAUMANN, F. W. PROSSER, JR., AND R. W. KRONE, *University of Kansas.*—The elastic scattering of protons from Na^{23} at an angle of 155° has been observed in the energy interval 780 kev to 1500 kev. Targets were made by evaporating metallic sodium onto thin organic backings inside the target chamber. A zinc sulfide screen and photomultiplier tube were used for particle detection. For some of the stronger resonances unambiguous spin and parity assignments were made. These resonance assignments are: $E_p=877$ kev, 1+; $E_p=1022$ kev, 2−; $E_p=1176$ kev, 1+; $E_p=1321$ kev, 3+, and $E_p=1398$ kev, 3+. Two strong resonances at $E_p=1288$ kev and $E_p=1460$ kev, which decay strongly by ground-state alpha particles, could not be given assignments compatible with those required for the observed angular distribution of the alpha particles. Simultaneously with the elastic scattering, the excitation curve for emission of ground-state alpha particles was obtained, verifying the results of Stelson[1] above 1 Mev. In addition three resonances, which show no evidence of gamma decay, at proton energies of 797 kev, 815 kev, and 922 kev were found which correspond to levels of Mg^{24} obtained by elastic scattering of alpha particles from neon.[2]

* Supported in part by the Office of Naval Research and the National Science Foundation.
[1] P. H. Stelson and W. M. Preston, Phys. Rev. **96**, 974 (1954).
[2] Goldberg, Haeberli, Galonsky, and Douglas, Phys. Rev. **93**, 799 (1954).

E2. Polarization in *P*-α Elastic Scattering.* MARY JEAN SCOTT† AND RALPH E. SEGEL,† *Brookhaven National Laboratory.*—The polarization of protons elastically scattered by alpha particles was observed by measuring the left-right asymmetry obtained by doubly scattering protons in helium. Protons at 3.0 Mev entered a helium filled double scattering chamber through a thin nickel window. Protons whose first scattering was at 90° (c.m.) and second scattering at ±73°, ±100°, and ±125° (c.m.) were detected by 50 μ Kodak NTA emulsions. The polarization was calculated from the ratio of the number of tracks on symmetrically placed plates using the formula: $R=(1+P_1P_2)/(1-P_1P_2)$ where P_1 and P_2 are the polarizations in the first and second scatterings, respectively. The resultant polarizations are compared below to those calculated from the single scattering phase shifts given by Critchfield and Dodder.[1] The two results are seen to be in agreement, with the error in the calculated polarizations being quite large due to the great sensitivity of the polarization to variations in the phase shifts.

R (observed)	P_1P_2 (observed)	P_1P_2 (calculated)
2.19±0.09	0.37±0.05	0.48±0.11
1.94±0.09	0.32±0.05	0.35±0.09
1.57±0.08	0.22±0.05	0.18±0.05

Preliminary data taken at an incident proton energy of 3.5 Mev indicate similar results.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Johns Hopkins University.
[1] C. L. Critchfield and D. C. Dodder, Phys. Rev. **76**, 602 (1949).

E3. *T*-*T* Elastic Scattering from 1.6 to 2.0 Mev. DALE M. HOLM AND H. V. ARGO, *Los Alamos Scientific Laboratory.*—A magnetically analyzed triton beam from an electrostatic generator has been scattered from tritium in a 14-inch scattering chamber and the differential cross sections measured in 10° steps from 20° to 140° in the c.m. system for incident energies of 1.8 and 2.0 Mev. Two proportional counters with a fixed angular separation of 90° were used in coincidence to detect both the scattered and recoil tritons for the laboratory angular range from 45° to 70°, with an absolute probable error of ±3%. A single counter was used for laboratory angles between 10° and 20°, with resultant probable errors of +5, −15%. Excitation functions in 100 kev steps from 1.6 to 2.0 Mev for c.m. angles of 60° and 90° show no evidence for an excited state in this region. The c.m. angular distributions in barns per steradian are as follows: 1.800 Mev: 20°, 2.90; 30°, 0.60; 40°, 0.1790; 50°, 0.1007; 70°, 0.0891; 80°, 0.0831; 90°, 0.0824. 2.013 Mev: 30°, 0.41; 40°, 0.159; 50°, 0.1103; 70°, 0.0815; 80°, 0.0881; 90°, 0.0795.

E4. Elastic Scattering of 40-Mev Alpha Particles from Light Nuclei.* G. IGO, H. E. WEGNER, AND R. M. EISBERG,* *Brookhaven National Laboratory.*—Thin foils of light and intermediate weight elements have been bombarded with alpha particles of energy 41±0.3 Mev. The angular distributions of elastically scattered alpha particles have been measured. In qualitative distinction to the differential cross section for elastic scattering of alpha particles from heavy elements, the lightest elements investigated show strong maxima and minima. The ratio, $(d\sigma/d\Omega)_{obs}/(d\sigma/d\Omega)_{Coul}$, oscillates about a value approximately equal to one. The quantity, $(d\sigma/d\Omega)_{Coul}$, is the cross section in the field of a point charge. In Cu and Al, the maxima occur at approximately ten degree intervals from 20° to 100°, the angular region investigated. The data for Cu and Al fit the diffraction formula: $kR\Delta(\sin\theta/2)=\pi/2$, where $R=1.3A^{\frac{1}{3}}+1.5$. In the intermediate weight elements such as Mo, the maxima and minima in $(d\sigma/d\Omega)_{obs}/(d\sigma/d\Omega)_{Coul}$ are less prominent and are superimposed on an exponentially decreasing function. The exponential decrease in Mo is comparable to the decrease[1] observed in elastic scattering from the heavier element, Ta, which shows no maxima or minima at this energy. A comparison will be made between these data and data taken at other energies.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Minnesota.
[1] Wegner, Eisberg, and Igo, Phys. Rev. **99**, 825 (1955).

E5. Absolute Cross Sections for the Coulomb Scattering of 1.00-, 1.75-, and 2.50-Mev Electrons.* V. SPIEGEL, JR.,† B. WALDMAN, AND W. C. MILLER, *University of Notre Dame.*—Electrons from our electrostatic generator were scattered from thin foils of aluminum, nickel, silver, and gold. The scattered electrons were analyzed by means of a 90° magnetic spectrometer using a scintillation detector. The cross sections were measured at 30°, 60°, and 90° with an estimated error of ±2% and at 120° and 150° with an estimated error of ±5%. A comparison of these results with the Mott theory as evaluated by Curr shows deviations of 5% to 10%, the experimental results being low. Corrections for nuclear size and screening and the radiative correction of Schwinger seem to be needed to remove this discrepancy.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the National Bureau of Standards.

E6. Plural Scattering of Fast Electrons.* B. WALDMAN, V. SPIEGEL, JR.,† AND W. C. MILLER, *University of Notre Dame.*—We have evaluated the effect of plural scattering in

our experiments on the Coulomb scattering of electrons. Electrons of energy 1.00, 1.75, and 2.50 Mev were scattered by aluminum, nickel, silver, and gold foils. The foils were in the transmission position for scattering angles of 30°, 60°, and 90°, and in reflection position for angles of 90°, 120°, and 150°. Data were taken as a function of foil thickness in the range 0.3 to 3 mg/cm². As expected the effect of plural scattering increased with decreasing electron energy and increasing atomic number.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the National Bureau of Standards.

E7. Nuclear Gamma-Ray Scattering Techniques.* G. E. PUGH, R. GOMEZ, D. H. FRISCH, AND G. S. JANES, *M. I. T.*—We have made further studies of an energy sensitive γ-ray detection system previously reported for use with scattered gamma rays in the 50 to 150 Mev range.[1] The system consists of a conventional gamma-ray telescope for identification, followed by a large liquid scintillation counter to measure the energy lost by an electron pair made in the lead converter by the gamma ray. A new telescope and large counter have been subjected to a more careful electron calibration using several converter thicknesses and many electron energies. This gives the telescope efficiency, somewhat lower at low energies than was previously assumed, as well as the pulse height response in the large counter. This data, together with the experimental pair cross sections, allows us to predict the response to an arbitrary gamma-ray spectrum. Assuming a bremsstrahlung distribution of gamma rays, the calculated response was in good agreement with the observed response when the counter was placed in the direct beam of the M. I. T. synchrotron. Difficulties of the order of 15% have arisen in our absolute normalization and are not yet understood.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Pugh, Frisch, and Gomez, Rev. Sci. Instr. **25**, 1124 (1954).

E8. Gamma-Ray Scattering by Complex Nuclei.* R. GOMEZ, G. E. PUGH, D. H. FRISCH, AND G. S. JANES, *M. I. T.*—Data is now available at 45° from several elements. In the pulse height region corresponding to 80-Mev gamma rays and above, the counting rate is a factor of two to three below that expected from a Thompson-type cross section. The cross section itself could dip to a considerably lower minimum and not be observed because of the width of the counter response. The low energy cross section at 45° is obscured by large numbers of low-energy gamma rays for which the counting rate is linear in target thickness. These produce a counting rate whose magnitude and dependence on angle, energy, and peak machine energy is consistent with a rough estimate of internal bremsstrahlung from pair creation. No theoretical calculation is available for comparison. The data at 90° and 135° also indicate some excess in scattering at low energy which may be attributed to the giant resonance.[1] After form factor correction, the high-energy data are almost consistent with Thompson, but there appears to be an excess of about 20 to 30% at 135° relative to 90°. Our knowledge of the radius and our absolute normalization may not be good enough to say which is out of line. It is probable that a systematic error in our previous data may have caused us to over-estimate the excess at 135°.[2]

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. Hayward, Proc. Photonuclear Conf., Case Institute of Technology, May 23, 1955, p. 23.
[2] Pugh, Frisch, and Gomez, Phys. Rev. **95**, 590 (1954).

E9. Gamma-Ray Scattering by Hydrogen.* G. S. JANES, R. GOMEZ, G. E. PUGH, AND D. H. FRISCH, *M. I. T.*—Using a liquid hydrogen target which will be described, we have observed scattered gamma rays at 50°, 90°, and 135°. The high counting rates observed by Oxley and Telegdi[1] at forward angles do not extend into our high energy channels at 50°. It is probable that they observed low-energy gamma rays of an origin similar to those described in the preceding abstract. At 90° and 135°, our low-energy data (50 to 90 Mev) is in agreement with Oxley and Telegdi, and with any reasonable theory. Our data above 90 Mev, at both 90° and 135°, suggests a somewhat lower cross section, but is not conclusive because of low counting rates.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] C. L. Oxley and V. L. Telegdi, Bull. Am. Phys. Soc. **30**, No. 5, 16 (1955).

E10. Preliminary Mass Doublet Measurements with the Minnesota 16-Inch Mass Spectrometer.* T. T. SCOLMAN, K. S. QUISENBERRY, AND A. O. NIER, *University of Minnesota.*—The 16-inch double-focusing mass spectrometer previously described[1,2] has been modified to employ the peak matching method.[3] This method utilizes an oscilloscope presentation which facilitates focusing the spectrometer since the mass peaks are instantaneously displayed. The frequency employed is approximately 30 cps which removes the necessity of obtaining long term stability of the electric and magnetic fields. This results in a considerable simplification in the electronic circuits. Resolving powers of 30 000 to 60 000 are usually employed although values as high as 100 000 have been obtained. A series of doublets have been measured to check the consistency of the spectrometer. These doublets and their tentative values are: $CH_4-O=36.3931\pm9$; $C_2H_4-CO=36.3926\pm8$; $C_3H_8-CO_2=72.7871\pm16$; $NH_2-O=23.8164\pm5$; $NH_3-OH=23.8159\pm6$; $CH_2-N=12.5730\pm8$; $CH_3-NH=12.5845\pm13$; $CH_4-NH_2=12.5800\pm5$; $C_2H_4-N_2=25.1585\pm6$; $N_2-CO=11.2356\pm6$. From these data, in addition to the measurement of the same doublet at various masses, two mass triplet cycles can be constructed and checked for closure.

* Supported by a grant from the National Science Foundation.
[1] Collins, Scolman, and Nier, Phys. Rev. **95**, 615 (1954).
[2] Quisenberry, Scolman, and Collins, Phys. Rev. **96**, 823 (1954).
[3] Clayton F. Giese and T. L. Collins, Phys. Rev. **96**, 823 (1954).

E11. The Atomic Masses of H^1, D^2, C^{12}, and S^{32}.* K. S QUISENBERRY, T. T. SCOLMAN, AND A. O. NIER, *University of Minnesota.*—The Minnesota 16-inch double-focusing mass spectrometer has been used to determine the atomic masses of H^1, D^2, C^{12}, and S^{32} relative to O^{16} by the doublet method. A series of mass doublets sufficient to give the mass of C^{12} by four different cycles has been measured. The doublets used and their tentative values are: $H_2-D=1.5498\pm1$; $CH_4-O=36.3931\pm5$; $D_2O-\frac{1}{2}A^{40}=41.9390\pm13$; $C_2H_4-A^{40}=68.9344\pm13$; $C_3-A^{36}=32.4729\pm20$; $H_2O-\frac{1}{2}A^{36}=26.7937\pm6$; $C_4-SO=33.0269\pm13$; $\frac{1}{2}C_4H_4O-H_2S=25.4016\pm12$; $O_2-S=17.7599\pm9$. An average of the four cycles gives the following tentative mass values: $H^1=1.0081439\pm5$; $D^2=2.0147380\pm10$; $C^{12}=12.0038174\pm18$; $S^{32}=31.9822401\pm9$. Comparison between these values and those obtained from nuclear reaction studies will be presented with particular attention given to C^{12}.

* Supported by a grant from the National Science Foundation.

E12. Nuclear Spin and Magnetic Moment of 50-Day In^{114m}. L. S. GOODMAN AND S. WEXLER, *Argonne National Laboratory.*—The nuclear spin, magnetic moment, and the sign of the magnetic moment of 50-day In^{114m} have been determined by the atomic beam magnetic resonance method.[1,2] The values found are $I=5\hbar$ and $\mu=+4.7$ n. m. Multiple quantum transitions[3] were observed in resonances of the inactive In^{115} used for the calibration of the magnetic fields. Some properties of these transitions and the limitation in accuracy of the determination of the nuclear magnetic moment of In^{114m} introduced by their presence will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Zacharias, Phys. Rev. **61**, 270 (1942).
[2] L. Goodman and S. Wexler, Phys. Rev. **99**, 192 (1955).
[3] P. Kusch, Phys. Rev. **93**, 1022 (1954).

FRIDAY AFTERNOON AT 2:15

Oriental 104

(W. H. ZINN presiding)

Apparatus and Techniques, II

Contributed Papers

G1. Monte Carlo Calculation* on Čerenkov Counters. TAKETORA YAMAGATA AND MEGUMU YOSHIMINE, *University of Illinois.*—In connection with recent developments of Čerenkov counters,[1] it was felt that they might be very suitable to measure with a fair accuracy the energy of high-energy photons and electrons. Computation on the response of such counters was performed with an electronic digital computor. Lead glass (n1.6, density 4) and $ZnBr_2$ water solution (n1.5, density 2.5) were chosen as media. A sequence of "random number," generated by the computor, determined the fate of an incident particle. All electrons and photons, produced in the medium by pairs, Compton effect and bremsstrahlung, were pursued until either they vanished, stopped or escaped. Čerenkov pulse heights were measured in units of visible quanta, and their distribution was presented for several energies (50 Mev to 1 Bev) and several counter thicknesses (2 to 40 radiation lengths). Measuring the incident energy in critical energy units and the thickness in radiation lengths, the results may be extended to other media. They may be useful to other problems like the response of scintillation counters and the efficiency of converters.

* R. R. Wilson, Phys. Rev. **86**, 261 (1952).
[1] M. H. L. Jester, UCRL 2990 (1955).

G2. Čerenkov Counter as High-Energy Photons Spectrometer. I. FILOSOFO, *University of Illinois.*—In the preparation of the equipment needed for an experiment on Compton scattering by protons at 200–300 Mev now in progress at Illinois, a large Čerenkov counter was designed and built as a detector of high-energy photons. The radiator was made of lead glass and designed following the evaluations made by Yamagata.[1] To detect the light emitted by the showers, two different kinds of phototubes were studied and compared. The counter was first tested by studying its response to cosmic rays. The pulses were recorded by a triggered oscilloscope. The counter was then tested and calibrated by using a fast electrons beam. This was obtained by deflecting through a focusing magnet the electrons emitted by a target exposed to 300-Mev rays. The distributions in the amplitude of the pulses obtained with cosmic rays and with electrons of different energies will be presented and compared with Yamagata's evaluations.

[1] See previous abstract.

G3. Microtron Injector for Electron Synchrotrons. H. F. KAISER, *Naval Research Laboratory.*—Use of the microtron as an electron injection device has been proposed by the author.[1,2] A design is described intended for a strong-focusing electron synchrotron with straight sections and which will have the specifications: (a) electron injection energies to 5 Mev, (b) on-orbit injection, and (c) no obstruction to the circulating beam. Since this injection system is more compact and less costly than available 2–5 Mev electron sources, its use is now contemplated in two instances known. The maximum possible yield which may be expected is estimated and a field cycle suitable for this method of injection is described. Large aperture at the input is achieved by a pole design which allows a wide separation of the final microtron orbit from the inner ones, with a weak magnetic field at the input. Magnetic deviation of the circulating beam is compensated in auxiliary correction fields. Preliminary experiments with available microtrons are described.

[1] H. F. Kaiser, Phys. Rev. **95**, 667(A) (1954).
[2] Kaiser, Mayes, and Willis, Phys. Rev. **98**, 1538(A) (1955).

G4. Small Model FFAG Betatron. I. General Description.* K. M. TERWILLIGER AND L. W. JONES, *University of Michigan*, F. T. COLE, *University of Iowa*, D. W. KERST, *University of Illinois*, AND R. O. HAXBY, *Purdue University and Midwestern Universities Research Association.*—The principles of FFAG accelerators[1] are being studied with a small betatron designed to accelerate electrons from 25 kev to 400 kev. The model is of the alternate field type, employing eight sectors. Each sector consists of two dc magnets producing fields equal in magnitude and opposite in direction, with the magnet giving positive curvature over twice as long as the one giving negative curvature. The radial dependence of the magnetic field is given by $H = H_0(R/R_0)^k$, where k has a constant value, 3.36, throughout the machine. In order to make equilibrium orbits of different energies geometrically similar, all pertinent magnet dimensions such as vertical aperture are scaled to be proportional to the machine radius. The proper increase in field with radius is then achieved by distributed pole face windings. The field is 40 gauss at the injection radius of 34 cm and increases to 134 gauss at the maximum radius of 49 cm, while the vertical magnet aperture increases from 4 to 6 cm over the same range. The alternating gradient focusing is designed to give 2.80 radial and 1.81 vertical betatron oscillations per revolution. A sinusoidally excited betatron core links the machine to produce a peak acceleration of 40 volts per turn.

* Supported by the National Science Foundation.
[1] K. R. Symon, Phys. Rev. **98**, 1152(A) (1955).

G5. Small Model FFAG Betatron. II. Design Calculations.* F. T. COLE, *University of Iowa*, AND D. W. KERST, *University of Illinois and Midwestern Universities Research Association.*—Analysis of orbits in the FFAG ring magnet described in the preceding abstract is complicated by the large fraction of circumference which is fringing field and by the dependence on "edge" focusing for vertical stability. We have developed approximate methods for finding the variation of field along the orbit and for discussing equilibrium orbits and small oscillations about these orbits in this field. Because orbits of different energies differ only by a scaling factor, we can write the guide field as $H(x,s) = H_0(x)F(s)$, where s is the arc length along the equilibrium orbit and x is the displacement perpendicular to that orbit. Then the orbit equations depend only on $F(s)$. We find an $F(s)$ by combining conformal mapping solutions of simpler problems. The equilibrium orbit is found by fitting together numerically orbits in different parts of the fringing field to form a closed orbit. The differential equations of oscillations about the closed orbit contain terms arising from the usual gradient focusing and terms arising from different path lengths in the field of particles of different amplitudes (edge focusing). We have solved these equations numerically and will discuss the physical interpretation of the results and final choice of magnet geometry.

* Supported by the National Science Foundation.

G6. Small Model FFAG Betatron. III. Preliminary Experimental Results.* L. W. JONES AND K. M. TERWILLIGER, *University of Michigan and Midwestern Universities Research Association.*—The wavelengths of the radial and vertical betatron oscillations in the FFAG model have been measured. The method used is to observe the position of two rays from a point electron source at similar points in successive sectors. Since an electron oscillation at similar points in successive sectors lies on a sine curve independent of its position elsewhere (by Floquet's theorem), a measurement of the spacing of two rays at similar points readily determines the wavelength The source, an injector with a pinhole, is placed at the center of a radial focusing magnet. A screen with two pinholes for each oscillation mode is put at the center of the next radial focusing magnet, defining the electron beams which are then observed on a fluorescent screen at the same point in the following sector. The measured wavelengths agree well with the calculated values. The betatron wavelengths can be tuned in this model by varying the relative strength of the positive and negative fields and by changing the field index, k. The tuning range is adequate to cross integral and half-integral resonances radially and vertically. The current status of the electron acceleration program will be discussed.

* Supported by the National Science Foundation.

G7. General Theory of Orbits in FFAG Accelerators. KEITH R. SYMON, *University of Wisconsin and Midwestern Universities Research Association.**—The magnetic field, and the character of betatron oscillations in a fixed field alternating gradient accelerator are determined if the equilibrium orbits are specified as a function of particle momentum. A suitable system of parameters for specifying a set of equilibrium orbits in a plane are introduced, and the equations for linear betatron oscillations about these orbits are derived. Two kinds of alternating gradient focusing terms appear, which may be referred to as "edge-type" and "gradient-type" focusing. Approximate formulas for betatron oscillation frequencies are derived relating them to momentum content, magnetic field flutter, and other machine parameters. The character of these relationships depends on whether the focusing is predominantly gradient-type or edge-type. An approximate treatment of nonlinear betatron oscillations can be given for machines whose equilibrium orbits are nearly circles.

* Supported by the National Science Foundation.

G8. FFAG Electron Cyclotron.* TIHIRO OHKAWA, *University of Illinois*† (introduced by D. W. Kerst).—New types of FFAG[1] accelerators having the same orbit length for all momenta are proposed. In these types electrons, injected with an energy of a few Mev, are accelerated by a fixed frequency electric field until the radiation loss becomes serious, probably at a few Bev. The necessary cavity voltage is, for example, 200 Kev with 3 Mev injection energy. Two types of guiding fields, similar to Mark I (alternate field type) and Mark V (spirally ridged type) are used. In both, the magnetic field increases exponentially in the vertical direction so that as the particle energy increases, its orbit rises vertically. The field also depends on the radius and the azimuthal angle in such a way that the focusing properties are very similar, respectively, to Mark I and to Mark V. Other types of FFAG having the orbit surface not on a median plane are also proposed.

* Reported by the present author at the meeting of the Physical Society of Japan in June, 1955.
† On leave from the University of Tokyo.
[1] Reported by the present author at the meeting of the Physical Society of Japan in October, 1953; K. R. Symon Phys. Rev. **98**, 1152(A) (1955).

Invited Papers

G9. Billion-Volt Injection into High-Energy Accelerators. L. C. TENG, *Argonne National Laboratory.* (30 min.)

G10. Cloud-Chamber Ionization Measurements and Applications. E. W. FRIESEN, *University of Indiana.* (30 min.)

FRIDAY AFTERNOON AT 2:15

Mandel Hall

(E. P. WIGNER presiding)

Invited Papers Derived from the Cosmic-Ray Congress at Guanajuato, Mexico

H1. The Primary Radiation and the Origin of Its Changes with Time. J. A. SIMPSON, *University Chicago.* (45 min.)

H2. Astrophysical Questions and the Galactic Origin of the Cosmic Rays. S. CHANDRASEKHAR, *University of Chicago.* (45 min.)

Contributed Paper

H3. Time Variation of Primary Heavy Nuclei Flux in the Cosmic Radiation.† M. KOSHIBA AND MARCEL SCHEIN, *University of Chicago.*—In view of the apparently conflicting experimental results on the subject thus far reported,[1] it is worthwhile to give the following new results. The sea-level data suggest a rather small variation, if any, of the high-energy heavy primaries.[2] However, we should note here that sea-level phenomena are appreciably affected by higher energy primaries only and that the lower energy region is where we might expect a sizeable time variation. As a consequence, the experiment should be carried out at higher geomagnetic latitudes and at the maximum possible altitude. This experi-

ment was performed at 58°N in a balloon which floated for 13 hours at an elevation of 100 000 feet. The technique of determining the time of arrival of the heavy nuclei was the same as that used by the Chicago group previously. The data thus far accumulated seem to show a similar time variation as that observed by V. H. Yngve.[3] Since the analysis is in full progress at the present time, more complete data will be presented with improved statistics.

† Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] T. H. Stix, Phys. Rev. **95**, 783 (1954).
[2] Lal, Peters, and Kaplon, Phys. Rev. **86**, 569 (1952).
[3] V. H. Yngve, Phys. Rev. **92**, 428 (1953).

Post-Deadline Papers, If Any

FRIDAY AFTERNOON AT 2:15

Eckhart 133

(G. BERNARDINI presiding)

Neutron Scattering and Absorption; Photoneutron Reactions

I1. Inelastic and Elastic Scattering of 1.7-Mev Neutrons.* S. D. BLOOM, G. N. GLASOE, C. O. MUEHLHAUSE, AND H. E. WEGNER, *Brookhaven National Laboratory.*—Neutrons of 1.67 Mev produced by proton bombardment of a $T-Zr$ target were scattered from various materials and the angular distriburions for both elastic and inelastic events were measured. Protons of 2.45 Mev were produced by the 18-in. BNL cyclotron in 2.5 mμsec bursts at 54 mμsec intervals. A focussed target current of 55 μamp was used for this work. The neutrons were detected with a plastic phosphor imbedded in a large LiF-Pb-CH_2 collimator. Neutron energy discrimination was achieved by the time-of-flight instrumentation described previously.[1] The ratio $R(\theta)=(d\sigma_s/d\Omega)/(d\sigma_i/d\Omega)$ was measured as a function of scattering angle for iron and is found to be strongly peaked in the forward and backward directions. For example, $R(45°, 90°, 135°)=(5.8, 2.6, 4.6)$. Preliminary data for other materials will be presented along with typical time-of-flight curves demonstrating the separation of the various neutron components.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Bloom, Muehlhause, and Wegner, Phys. Rev. **99**, 654 (1955).

I2. Slow Neutron Resonance Scattering of U^{235}.* H. L. FOOTE, JR., *Brookhaven National Laboratory.*—The scattering cross section of U^{235} as a function of energy has been observed over the range 0.27 to 2 ev. A "thick-thin" target geometry[1] and a crystal spectrometer were used to make the measurements. The results obtained will be presented and discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. L. Foote, Jr., and J. Moore Phys. Rev. **98**, 1161(A) (1955).

I3. Neutron Transmission Measurements on Br and Se. J. M. LEBLANC, L. M. BOLLINGER, AND R. E. COTÉ,* *Argonne National Laboratory.*—The neutron resonance structure of Br and Se have been studied with the Argonne fast chopper. The resolution used was about 0.08 μsec/m. A new Argonne chopper was also used for part of the measurements. Isotopic identification was made for some of the stronger resonances. The normal Br samples were in the form of liquid Br or liquid Br dissolved in CS_2. Neutron resonances with energies of 35.6, 54.2, 102, 134, 190, 205, 240, 295, and 317 ev were resolved in normal Br. The resonances which were identified as due to Br^{79} have energies of 35.6, 54.2, 190, 240, and 317. Those resonances assigned to Br^{81} have energies of 102 and 134. Transmission dips with energies of 553, 669, and 1540 ev were found to be characteristic of Br^{81} but because of the high level density in Br individual resonances were probably not completely resolved at energies greater than about 350 ev. The neutron transmissions of normal Se metal and enriched Se^{77} Se^{78}, and Se^{80} were measured in the energy interval up to about 10 kev. The resonances whose isotopic assignments have been made are 211 ev (77), 660 ev (77), 960 ev (77), 1830 ev (80), 4100 ev (80), and 5350 ev (80). The parameters for several resonances in Br and Se will be given.

* Work done under the auspices of the U. S. Atomic Energy Commission.

I4. The Absorption Cross Section of Gold for Slow Neutrons Measured on a Single Crystal Spectrometer.* F. T. GOULD, T. I. TAYLOR, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—Columbia University's single crystal spectrometer, at the Brookhaven National Laboratory, has been adapted to work in the 4 to 8.75 A region. A mica crystal is used as monochromator and combinations of Be, BeO, and Bi are used as filtering materials. The gold cross section has been measured in the region 4.9 to 8.75 A and is in excellent agreement with results obtained by other methods.[1] A least squares fit of forty-six points to a straight line gives a slope of 54.40 b/A±0.05. The wavelength calibration based on the graphite, bismuth, beryllium, and beryllium oxide breaks is known to 0.2%. Within this accuracy, the gold cross section follows a 1/v law in the measured wavelength interval. To obtain the thermal absorption cross section, we can make an accurate correction (1.2%) for the departure from 1/v at $E=0.025$ ev, since 95% of the thermal cross section comes from the 4.9 ev level.[2] The 2200 m/sec absorption cross section is then $\sigma_{abs}=99.0\pm2.0$ barns.

* Research performed under contract with the U. S. Atomic Energy Commission.
[1] Carter, Palevsky, Myers, and Hughes, Phys. Rev. **92**, 716 (1953).
[2] Wood, Landon, and Sailor, Phys. Rev. **98**, 639 (1955).

I5. Neutron Total Cross Section of $_{92}U^{235}$ in the ev Region.* V. E. PILCHER, J. A. HARVEY, AND K. K. SETH,† *Brookhaven National Laboratory.*—The neutron total cross section of $_{92}U^{235}$ has been studied in the energy range 2 ev to 40 ev, using the Brookhaven fast chopper. The resonances in this isotope are rather small and extremely closely spaced. The average level spacing of 1.3 ev/spin state is the smallest yet reported in any isotope. This spacing is based on the number of levels up to 20 ev, since above this energy it is not always possible to separate individual resonances with the present resolution. The Breit-Wigner parameters were computed for all of the observed resonances, making use of the area method of analysis. In cases where it was not possible to obtain Γ from thick and thin sample measurements, the quantity $g\Gamma_n$ was computed from the thin sample data, making use of an average Γ of 0.1 ev. The ratio $\bar{\Gamma}_n^0/D$ is $(0.9\pm0.2)\times10^{-4}$. This is somewhat larger

than is predicted by the cloudy crystal-ball theory. The size distribution of the reduced neutron width has been determined and compared with present theories. By combining the fission data with the total cross-section data it was possible to obtain values of Γ_γ for several of the low-energy resonances. The average value for Γ_γ was found to be 30 ± 6 mv. Making use of this value of Γ_γ the quantity Γ_f was calculated for those resonances in which Γ was known.

* Work carried out under contract with U. S. Atomic Energy Commission.
† Summer student from the University of Pittsburgh Radiation Laboratory.

I6. Neutron Resonances in U^{233} and U^{235}.* V. L. SAILOR, *Brookhaven National Laboratory.*—The total cross sections of U^{233} and U^{235} have been measured with a high resolution crystal spectrometer over the range of energies from 0.1 to >10 ev. The highly complicated resonance structure has been analyzed and Breit-Wigner parameters for each resonance will be presented. Evidence has been found for interference between resonances in the fission component of the cross section. This and other special features of these cross sections will be discussed.

* Research supported by U. S. Atomic Energy Commission.

I7. Neutron Resonance Parameters and Total Cross Sections in U^{235}.* O. D. SIMPSON, R. G. FLUHARTY, F. B. SIMPSON, AND R. M. BRUGGER, *Phillips Petroleum Company.*—Total cross sections of U^{235} have been measured from 10 ev to 10 kev with a resolution of 0.05 to 0.07 μsec/meter using the Materials Testing Reactor (MTR) Fast Chopper, and resonances have been studied below 60 ev. Breit-Wigner (BW) parameters for more than 50 resonances have been obtained from transmission data. New resonances have been found at 28.8 ev, 29.4 ev, and 30.0 ev. The 25.7-ev and 35.3-ev resonances, reported by Brookhaven National Laboratories (BNL), have each been split into two components: (25.7, 26.1) and (35.0, 35.7), respectively. Other resonances reported by BNL show strong indications of being split: 13.3 ev (13.0, 13.3), 14.1 ev (13.9, 14.1), 14.6 ev (14.5, 14.7), and 15.4 ev (15.3, 15.5). Some of the resonances above 35.7 ev for which $\sigma_0\Gamma$ values will be reported are: 38.8, 40.1, 42.6, 44.2, 45.4, 47.7, 49.2, 52.3, 56.1, 57.3, 59.2, and 61.4 ev. Values of $\sigma_0\Gamma^2$ have been determined where "thick-thin" sample data were obtained. Although it is likely that many levels above 12 ev have not been resolved, BW area analyses have been made. Parameter values for some of these resonances cannot be given great weight, and higher resolution will be required at these energies before good answers can be obtained for this important reactor fuel (the level spacing is one of the smallest so far observed).

* Work performed under the auspices of the U. S. Atomic Energy Commission.

I8. Measurement of $\bar{\Gamma}_n^0/D$ Ratio by Average Cross Sections.* D. J. HUGHES AND V. E. PILCHER, *Brookhaven National Laboratory.*—The ratio of the average neutron width of slow neutron resonances to the level spacing, or "strength function," is a quantity of importance to current nuclear models. This ratio can be obtained[1] from the widths and spacings measured for individual levels but the accuracy is limited by the small number of levels that can be analyzed. However, if the average total cross section in the region 1 to 5 kev is measured with a sample so thin that no self-absorption is present, the result, after subtraction of potential scattering, gives $\bar{\Gamma}_n^0/D$ directly (in fact, at 1 kev is simply 12.9×10^4 $\bar{\Gamma}_n^0/D$ barns). This method has been tested, using the Brookhaven fast chopper, for Ag, Th, U, and Ta. The potential scattering contribution to the cross section has been eliminated by measurement of transmission for a series of sample thicknesses. The results obtained, in units of 10^{-4} are Th, 0.9 ± 0.2; U, 1.1 ± 0.2; Ag, 0.30 ± 0.06, Ta, 1.9 ± 0.2. These $\bar{\Gamma}_n^0/D$ ratios are in good agreement with the results obtained[1] from individual resonances and are of higher accuracy.

* Work carried out under contract with U. S. Atomic Energy Commission
[1] Harvey, Hughes, Carter, and Pilcher, Phys. Rev. **99**, 10 (1955).

I9. Photoneutron Angular Distribution from Carbon. B. P. FABRICAND, B. ALLISON, AND J. HALPERN, *University of Pennsylvania.*—Previous measurements[1] of the photoproton angular distribution arising from the giant dipole resonance in the reaction $C^{12}(\gamma,p)B^{11}$ have yielded a distribution of the form $2+3\sin^2\theta$. This has been interpreted[2] as evidence for an independent particle description of the giant resonance and for the *LS* coupling scheme. In the hope of studying the process of the direct emission of photoneutrons, we have measured the angular distribution of neutrons from the giant dipole resonance in the reaction $C^{13}(\gamma,n)C^{12}$ using a zinc sulfide-paraffin-plastic scintillator as the neutron detector. In contrast to the results for photoprotons from carbon, the photoneutrons show a dip at 90° and a distribution that can be fitted by an expression of the form $a+b\cos^2\theta$. The results will be analyzed from the standpoint of distributions expected from the possible channel spins involved.

[1] Halpern, Mann, and Rothman, Phys. Rev. **87**, 164 (1952).
[2] Mann, Stephens, and Wilkinson, Phys. Rev. **97**, 1184 (1955).

I10. The Photoneutron Effect in Zr^{90} Very Near Threshold.* JOHN D. FOX AND PETER AXEL, *University of Illinois.*—The reactions $Zr^{90}(\gamma,n)Zr^{89}$ and $Zr^{90}(\gamma,n)Zr^{89m}$ have been studied in detail near threshold. The threshold for the production of Zr^{89m} is 12.37 ± 0.09 Mev. The shapes of the activation functions are interpreted by using the neutron transmissions derived from the strong absorption model, the gamma ray and reduced neutron widths as measured by neutron scattering methods.[1] and by assuming that the compound nucleus is formed in the reactions. Analysis of the data leads to an estimate of the amount of each type of process by which the incident photon is absorbed $-E2$, $E1$, or $M1$. If there is no $M1$ absorption, 60% of the absorption is of the $E1$ type; if $M1$ and $E2$ absorption occur equally, only about 10% of the absorption is $E1$. The familiar shape of photoneutron activation functions: $Y(E_\beta)\propto(E_\beta-E_{th})^2$ can be explained by assuming that large amounts of $E2$ or $M1$ absorption take place in the threshold region and that $E1$ absorption is much less important.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Harvey, Hughes, Carter, and Pilcher, Phys. Rev. **99**, 10 (1955).

I11. Mg(γ,n) Cross Section. PAUL F. YERGIN AND BURTON P. FABRICAND, *University of Pennsylvania.*—The published data[1,2] for natural Mg and for Mg^{25} disagree somewhat in the energy region below 11 Mev where only $Mg^{25}(\gamma,n)$ can contribute to the neutrons detected. Above the $Mg^{26}(\gamma,n)$ threshold at 11.1 Mev, however, a more serious disagreement occurs. If the measured Mg^{25} yield is subtracted from the published natural Mg yield, the resulting "$Mg^{26}(\gamma,n)$" cross section from its threshold to the $Mg^{24}(\gamma,n)$ threshold at 16.6 Mev, is extremely different from that of Mg^{25} in the same region. We have investigated this by remeasuring the natural $Mg(\gamma,n)$ cross section, using a sample of MgO. Our yields disagree with the published values in the region in question. If the Mg^{25} yield is subtracted from our measured natural Mg yield, the resulting "$Mg^{26}(\gamma,n)$" yield resembles very closely that of Mg^{25} in the same region. Spectroscopic analysis of our sample showed no significant impurities.

[1] Katz, Haslam, Goldenberg, and Taylor, Can. J. Phys. **32**, 580 (1954).
[2] R. Nathans and P. F. Yergin, Phys. Rev. **98**, 1296 (1955).

FRIDAY AFTERNOON AT 2:15

Cobb 110

(E. FEENBERG presiding)

Theoretical Physics, II

K1. A Torus Model of the Elementary Particles in which Stability May Be Achieved by Gravitational Forces Resulting from the Concentrated Electromagnetic Field.* WINSTON H. BOSTICK,† *University of California, Livermore.*—For a simple torus model of an elementary "particle" the total rest energy m_0c^2 can conceivably be equated to the sum of the electromagnetic-field energy $E_f(=e^2(\ln R/r_0)/\pi R)$ and the gravitational energy $E_g(=-Ge^4(\ln R/r_0)^3/\pi^3c^4R^3)$, where R and r_0 are the major and minor radii of the torus, and G is the gravitational constant. Entities where $|E_g|\ll|E_f|$ may be expected to be unstable. It is suggested that these entities be identified with the mesons; e.g., $\ln R/r_0\cong 180$ for the π^- meson. Entities where $|E_f|=|E_g|$, i.e., $m_0c^2=0$, may possibly correspond to photons and neutrinos. Entities where $|E_g|\cong|E_f|$ represent the possible condition of highly dynamic stability and may conceivably correspond to the electron and the proton ($\ln R/r_0\cong 5\times 10^{10}$). A truly "bound state" corresponds to $|E_g|>|E_f|$, or a negative value of m_0c^2, the interpretation of which presents difficulties. The correspondence of this model to the quantum mechanical wave function and a suggested role of the model in nuclear structure will be briefly discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from Tufts College, Medford, Massachusetts.

K2. Bending of Light and Falling Rotators.* F. J. BELINFANTE, *Purdue University.*—Consider a linear theory of gravitation[1] yielding a bending fGM/c^2R of light passing sun mass M (with $f=4$ for Einstein). A particle traveling in the earth's field $\mathbf{g}$ then experiences an acceleration $\mathbf{a}_0=\mathbf{g}[1+(f/2-1)v^2/c^2]-f\mathbf{v}(\mathbf{v}\cdot\mathbf{g})/c^2$. Due to the v^2/c^2 terms, why do not heavy elements (with fast nucleon motion inside nucleus) fall faster than hydrogen? The acceleration of a charge in the gravitational field is $\mathbf{a}=\mathbf{a}_0+(1-v^2/c^2)^{\frac{1}{2}}(e/m_0)\{(\mathbf{E}+\mathbf{v}\times\mathbf{B}/c)[1+h(1-f-fv^2/2c^2(1-v^2/c^2))]-\mathbf{v}(\mathbf{v}\cdot\mathbf{E}/c^2)[1+h-fhv^2/2c^2(1-v^2/c^2)]\}$, where $h=GM/c^2R\approx h_0+\mathbf{g}\cdot\mathbf{x}/c^2$. Neglecting radiative effects not due to a yet undetermined gravitational acceleration $\mathbf{a}_{g1}$, the Coulomb field, from a charge e_1 at $\mathbf{x}_1$, is $\mathbf{E}\approx e_1r^{-3}\mathbf{r}[1-fh_0/2-f\mathbf{g}\cdot\mathbf{x}_1/2c^2-(f\mathbf{g}/2+\mathbf{a}_{g1})\cdot\mathbf{r}/2c^2]+e_1r^{-1}(f\mathbf{g}/2-\mathbf{a}_{g1})/2c^2$. The helical motion $\mathbf{x}_2(t_2)$ of particle e_2 in the field of e_1, and vice versa, is obtained from the unperturbed circular motion $\xi(\tau)$ by transformation $\mathbf{x}=\xi[1+(1-f/2)h]+(f/2-1)\mathbf{g}\xi^2/2c^2+\mathbf{a}_g t^2/2$, and $t=(1+h)\tau$, *if* $\mathbf{a}_{g1}=\mathbf{a}_{g2}=\mathbf{g}$, showing that such rotating dipole falls with gravitational acceleration $\mathbf{g}$ (and not $\mathbf{a}_0$) for any value of the constant f.

* Supported by National Science Foundation.
[1] F. J. Belinfante and J. C. Swihart, N.S.F. research report, Purdue University, September, 1954.

K3. Hartree-Fock Wave Functions for Mn^{+4}. W. W. PIPER AND J. S. PRENER, *General Electric Research Laboratory.*—Hartree-Fock one-electron wave functions have been obtained for the ground state (^1F) of Mn^{+4}. Hartree's interpolated wave functions[1] for Mn^{+2} were used as initial estimates for the filled shells. An approximate solution for the ($3d$) wave function was available from previous work. An IBM type 650 digital computer was utilized to carry out the computation. The differential equations were integrated by means of Numerov's difference equation[2] for second-order differential equations. Simpson's rule was used for all quadratures. A total of fifteen iterations on various individual shells were carried out. This required approximately five hours of valid machine time. The total charge belonging to any shell and included within a sphere of arbitrary radius is correct to less than 0.005 a.u. The position of the maximum in the ($3d$) wave function is 0.72 a.u. which is 0.10 A smaller than the radius reported by Hartree[1] for Mn^{+2}. Work is in progress on the lowest excited state (^1P).

[1] D. R. Hartree, Proc. Cambridge Phil. Soc. **51**, (Part 1) 126 (1955).
[2] B. Numerov, Publ. de Observ. astrophysi. central Russ. **2**, 188 (1933).

K4. A Positional Correlation Study for a System of Two Electrons.* J. S. EVANS AND R. H. TREDGOLD, *University of Maryland* (introduced by R. D. MYERS).—A system of two electrons harmonically bound to a mass much larger than their own is one of the few three-body problems which is amenable to exact solution. Such a model provides a convenient check on various approximations used to handle correlation problems whereas heretofore it has been necessary to appeal to experiment. The ground-state eigenvalue and eigenfunction have been calculated exactly and by several approximate methods. Comparison of the exact and approximate wave functions allows one to obtain a better insight into the shortcomings of the approximate methods than is obtained by the usual comparison of eigenvalues.

* Supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

Invited Papers

K5. Effective-Range Theory of Meson-Nucleon Scattering. FRANCIS LOW, *University of Illinois.* (30 min.)

K6. Theory of Pion Photoproduction. MARC ROSS, *Indiana University.* (30 min.)

K7. Higher-Spin Particle Formalism. D. C. PEASLEE, *Purdue University.* (30 min.)

K8. On the Relation of a Potential to the *S*-Matrix. R. G. NEWTON, *Indiana University.* (30 min.)

FRIDAY AFTERNOON AT 2:15

Kent 106

(JOHN BARDEEN presiding)

Invited Paper

N1. Energy-Band Structure of Solids with ZnS-Type Lattices. G. DRESSELHAUS, *University of California, Berkeley.* (30 min.)

Semiconductors, I

N2. Thermoelectric Power in a Semiconductor Showing High-Temperature Degeneracy. V. A. JOHNSON, *Purdue University.*—The narrowness of the forbidden energy band in intermetallic compounds makes it probable that the electron gas at room temperature and above will be sufficiently degenerate to require the use of Fermi-Dirac statistics in expressions for the electrical properties. The thermoelectric power of a semiconductor obeying Fermi-Dirac statistics, considering both holes and electrons, is

$$Q=-\frac{k}{e}\frac{\begin{array}{r}2c^{3/5}J_0(-\zeta^*-E_G^*)J_{\frac{1}{2}}(\zeta^*)J_{\frac{1}{2}}(\zeta^*)\\ -2J_1(-\zeta^*-E_G^*)J_{\frac{1}{2}}(-\zeta^*-E_G^*)J_0(\zeta^*)\end{array}}{\begin{array}{r}c^{3/5}J_0(\zeta^*)J_0(-\zeta^*-E_G^*)J_{\frac{1}{2}}(\zeta^*)\\ +J_0(\zeta^*)J_0(-\zeta^*-E_G^*)J_{\frac{1}{2}}(-\zeta^*-E_G^*)\end{array}}$$

$$+\frac{k}{e}\frac{c^{3/5}\zeta^*J_{\frac{1}{2}}(\zeta^*)+(\zeta^*+E_G^*)J_{\frac{1}{2}}(-\zeta^*-E_G^*)}{c^{3/5}J_{\frac{1}{2}}(\zeta^*)+J_{\frac{1}{2}}(-\zeta^*-E_G^*)}$$

if only lattice scattering by acoustical modes is present. $J_k(\zeta^*)$ is a Fermi-Dirac integral, ζ^* the reduced Fermi level, E_G^* the reduced value of the forbidden band width, and c the electron-to-hole mobility ratio. Fan and Spitzer[1] have found optical evidence for the combination of acoustical and optical modes of scattering in indium antimonide. Hence the thermoelectric power for optical mode scattering and Fermi-Dirac statistics has also been calculated and found to differ considerably from the preceding case.

[1] W. G. Spitzer and H. Y. Fan, Phys. Rev. **99**, 1893 (1955).

N3. Ionized Impurity Scattering in Semiconductors. FRANK S. HAM,* *University of Illinois.*—The Brooks-Herring analysis of the scattering of electrons or holes by ionized impurities has been generalized for ellipsoidal energy surfaces. From the effective mass approximation we find for ellipsoidal surfaces, as well as for spherical surfaces, that an electron is scattered from a state with propagation vector $\mathbf{k}$ to a state $\mathbf{k}'$ of equal energy with a probability proportional to $[(\mathbf{k}-\mathbf{k}')^2+1/\lambda^2]^{-1}$, where λ is the Debye screening length. However, for an ellipsoidal surface with an axis of symmetry the resulting relaxation times appropriate to conductivity along and perpendicular to the axis may be quite different. For a mass ratio $m_s/m_t=19$ appropriate to the conduction band of Ge, the relaxation time ratio τ_s/τ_t is about 12 if only small angle scattering is important and if lattice scattering can be neglected. The corresponding ratio for Si is 4 for $m_s/m_t=5.1$. Results for the contribution of large angle scattering will be presented, together with those for combined lattice and impurity scattering.

* NRC Fellow, 1954–1955. Now at the General Electric Research Laboratory.

N4. Infrared Properties of Selenium. R. S. CALDWELL AND H. Y. FAN, *Purdue University.**—Optical properties of liquid, amorphous, and crystalline selenium were investigated. In agreement with previous measurements, the absorption edge varies continuously throughout the liquid and solid amorphous phases by 1.4×10^{-3} ev/degree, between 140°K and 580°K. At the low absorption levels measured in the experiments, the absorption edge in the hexagonal phase is at about the same position as in the amorphous phase, and no significant difference was found by using radiation polarized parallel or perpendicular to the C-axis. The two absorption bands, at 13.5μ and 20.4μ, in amorphous selenium were observed also in the liquid phase at slightly longer wavelengths; this shift can be attributed to the temperature difference. The hexagonal phase shows a doublet band at 21.5μ. At long wavelengths, strong bands were observed around 35μ and 80μ in amorphous, and around 27μ and 70μ in crystalline samples. The reflectivity of amorphous selenium is 17.5% corresponding to the known refractive index of 2.45. The refractive indices in hexagonal selenium are $n_\perp=2.78$ and $n_\parallel=3.58$, constant in the range of measurement, 9μ to 23μ. These were measured using interference effect in thin samples.

* Supported by a Signal Corps Contract.

N5. Mechanical Properties of Si, Ge, and ZnO Whiskers. G. L. PEARSON, W. T. READ, JR., AND W. L. FELDMANN, *Bell Telephone Laboratories.*—Silicon whiskers 20μ in diameter and 2 mm long were supported at the two ends and bent by a concentrated load applied in the center through a quartz fiber hook. From 30°C to 600°C the behavior was elastic up to fracture at a maximum stress of about 2×10^{10} dynes cm^{-2}. The yield stress varied from 2×10^{10} at 600°C to 4×10^{9} at 800°C. During yielding in a hard machine, the force dropped to 0.3–0.5 times the yield force and thereafter remained constant during flow. For a given center deflection, maximum whisker curvature decreased and the length of the deformed region increased with temperature. Under constant load at 800°C yielding occurred after incubation; the creep-time curve was S-shaped, reaching a constant deflection. Pure tension and bending gave the same room temperature fracture stress. In germanium, log yield stress varied linearly with temperature with a slope of one decade per 135°C for both whiskers and bulk specimens. The fracture stress of the whiskers was 1.2×10^{10} dynes cm^{-2} and the minimum temperature for plastic deformation, 350°C. ZnO whiskers fractured at 1.5% elastic strain. The interpretation of the results will be discussed. These Si, Ge, and ZnO whiskers were furnished by J. A. Ditzenberger, H. Christensen, and D. G. Thomas, respectively.

N6. Hall Effect in Gray Tin Filaments.* E. E. KOHNKE† AND A. W. EWALD, *Northwestern University.*—To supplement a previous study of the conductivity and magnetoresistance of filamentary gray tin specimens,[1] a method for mounting the filaments to allow measurement of the Hall coefficient in the temperature range 70° to 270°K has been devised and results obtained for a number of n-type and p-type samples. It is shown that the mobility expressions $\mu_n=30.2\times10^6T^{-1.65}$, $\mu_p=21.8\times10^7T^{-2.0}$ cm^2/volt sec and the impurity concentration $N=2.5\times10^{17}$ cm^{-3} provide a very satisfactory fit to experimental data for the conductivity and Hall coefficient of a pure sample (n-type) down to 170°K. The indicated

absolute zero energy gap is 0.094 ev and an assumed energy gap temperature dependence leads to $M_e = M_h = 0.68$ M. In contradiction, p-type samples show mobility ratios greater than unity but in no specimens studied is there evidence of high mobility ratios comparable to those generally reported in InSb. A shift of the Hall crossover to higher temperatures with increasing field strengths is noted.

* Work supported by the Office of Naval Research.
† Now at Oklahoma A & M College, Stillwater, Oklahoma.
[1] A. W. Ewald and E. E. Kohnke, Phys. Rev. 97, 607 (1955).

N7. Measurement of Magnetic Field Gradients by the Hall Effect.* R. D. REDIN AND G. C. DANIELSON, *Iowa State College.*—A magnetic field gradients measuring device, which uses the Hall effect in germanium, has been constructed. The field sensitive element is a bar of germanium 1 mm by 1 mm by 12 mm with two sets of Hall leads attached 2 mm either side of its center. One-hundred-cycle alternating current flows in the long direction of the bar. In a magnetic field two 100-cycle Hall voltages are obtained. These voltages, which are proportional to the magnetic field strength at two points of the field 4 mm apart, are subtracted to give an output directly proportional to the magnetic field gradient. The instrument will also measure field strengths and relative gradients. The instrument was tested in a calculable magnetic field produced by step pole pieces. Gradients from 5 gauss/inch to 500 gauss/inch in magnetic fields below 5000 gauss were measured. The usefulness of the instrument is still uncertain owing to errors caused by excessive field dependence of the gradient voltage.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

FRIDAY EVENING AT 7:00

Quadrangle Club

(R. T. BIRGE presiding)

Banquet of the American Physical Society

After-dinner speakers to be announced.

SATURDAY MORNING AT 9:00

Oriental 104

(R. G. HERB presiding)

Reactions of Transmutation and Nuclear Energy Levels, I

P1. The T(d,n)He^4 Reaction, 1–5 Mev. C. H. JOHNSON AND A. GALONSKY, *Oak Ridge National Laboratory.*—Neutrons were produced in the T(d,n)He^4 reaction by bombardment of a tritium gas target with deuterons from the 5.5-Mv electrostatic generator. The monoenergetic neutron spectrum was observed in a radiator-type triple coincidence spectrometer consisting of 2 proportional counters and a NaI crystal. With both a target thickness and deuteron energy increment of 50–100 kev the 0° cross section was measured from $E_d = 1$ to 5 Mev. No sharp resonance is observed within this energy range. The 0° c.m. cross section continues to drop with increasing energy from the well-known resonance at 107 kev to 11 mb/sterad at 2.5 Mev and then rises steadily to 18 mb/sterad at 5 Mev. The total cross section decreases to 76 mb at 3.5 Mev and increases to 82 mb at 5 Mev. This increase may indicate a resonance. Angular distributions were measured from 0° to 150° at $E_d = 1.53$, 2.20, 3.05, 3.97, 4.98, and 5.79 Mev. A forward peak, which is slight at the lower energies, becomes steadily sharper with increasing energy. At 5.79 Mev the peak (0°) to valley (100°) cross-section ratio is 5:1 in the c.m. system. Beyond 100° the cross section rises by less than a factor of 2. At no energy is there symmetry about 90°.

P2. Gamma Rays from He^3 Bombardment of Deuterium. W. E. KUNZ, J. W. BUTLER, AND H. D. HOLMGREN.—Deuteron capture by He^3 [1] was confirmed by bombarding a deuterium gas target with a He^3 beam and observing the gamma-ray spectrum with a 3 in.×3 in. NaI crystal and a 20 channel pulse-height analyzer. Background gamma rays from the high-energy protons produced by the He$^3(d,p)$He^4 reaction gave peaks about 250 times that due to the deuteron capture gamma ray. With a polyethylene (CH_2) liner for the target chamber the most intense gamma ray was 4.43 Mev from protons inelastically scattered by carbon. A gold liner gave a continuous distribution of gamma rays with a maximum energy considerably higher than 4.43 Mev. For this reason a polyethylene liner was used for the remainder of the experiment. The gamma rays from deutron capture are not monoenergetic but have an energy spread of at least several Mev with a cut-off at approx 16.5 Mev. The ratio of gamma-ray yield to proton yield from the He$^3(d,p)$He^4 reaction is not a constant but increases at energies above the resonance of the proton reaction.

[1] Blair, Hintz, and Van Patter, Phys. Rev. 96, 1023 (1954).

P3. Alpha Spectrum from Li$^7(p,\gamma)$Be$^{8*}(\alpha)$He^4.* E. C. LAVIER, S. S. HANNA, AND R. W. GELINAS, *Johns Hopkins University.*—States in Be^8 at 4.1, 5.3, and 5.7 Mev have been reported[1] from observations on the Li$^7(p,\gamma)$Be$^{8*}(\alpha)$He^4 reaction. We have observed the alpha spectrum up to $E_\alpha = 11$ Mev with magnetic analysis at $^*E_p = 0.44$ Mev. Thin Li^7 targets were employed and the resonance reaction was monitored with the gamma radiation. Four exposures of 20–30 hours each were made to cover the spectrum. The following groups were observed: The broad structure corresponding to

the 2.9-Mev state in Be^8, the alpha and He^3 groups in the $Li^6(p,\alpha)He^3$ reaction from the small amount of Li^6 in the target, and a weak alpha group attributed to $O^{18}(p,\alpha)N^{15}$ from oxygen contamination of the target. In analyzing the alpha spectrum for possible structure which could be attributed to the existence of higher states in Be^8, it is necessary to consider the recoil motion imparted to the Be^8 nucleus by the gamma emission. We estimate that a group at $E=2.0,2.6$, or 3.7 Mev would have been observed if its intensity was greater than 1.0, 0.7, or 0.5% of the total alpha spectrum.

* Assisted by a contract with the U. S. Atomic Energy Commission.
[1] E. K. Inall and A. J. F. Boyle, Phil. Mag. **44**, 1081 (1953).

P4. Search for States in Li^7 and Be^9.* R. W. GELINAS AND S. S. HANNA, *Johns Hopkins University.*—Recently evidence has been reported for the existence of a state in Li^7 at 5.5 Mev.[1] Using the $Be^9(d,\alpha)Li^7$ reaction with magnetic analysis we have searched through a region up to $E_{ex}=6.0$ Mev in Li^7. Bombarding energies were 0.50 and 0.70 Mev and the angle of observation was 70°. No particle group was observed which could not be attributed to previously well-established reactions. The Li^7 state at $E_{ex}=4.62$ Mev was resolved in several spectra. The $Be^9(d,t)Be^8$ reaction was also investigated at angles from 23° to 90° and bombarding energies from 0.47 to 1.15 Mev in order to look for a state in Be^8 at 4.0 to 4.3 Mev In this instance also a negative result was obtained.

* Assisted by a contract with the U. S. Atomic Energy Commission.
[1] Erdos, Scherrer, Stoll, Wachter, and Wataghin, Nuovo cimento **12**, 639 (1954).

P5. The Reactions $Be^9(d,d')$ and $Be^9(\alpha,\alpha')$.* D. W. MILLER, V. K. RASMUSSEN, M. B. SAMPSON, AND U. C. GUPTA, *Indiana University.*—The existence of a level in Be^9 at 3.01 ± 0.1 Mev has been verified by the inelastic scattering of 21.6-Mev alpha particles and 10.8-Mev deuterons. A broad continuum of inelastic particles near 1.8-Mev excitation is found from both reactions. If one assumes that an uncorrelated three-body breakup of the compound nucleus causes the broad continuum, then the superimposed peak represents a level in Be^9 at 1.74 ± 0.1 Mev. However, within the accuracy of the present data, the observed spectrum is consistent with a three-body breakup in which a final-state potential-scattering interaction[1] between the Be^8 and the neutron occurs (scattering length about 1.3×10^{-12} cm. The existence of a state in Be^9 around 1.8 Mev is then allowed, but not required.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] K. M. Watson, Phys. Rev. **88**, 1163 (1952).

P6. Angular Distribution of Protons from $Be^9(He^3,p)B^{11}$ Reaction. H. D. HOLMGREN, W. E. KUNZ, AND L. BULLOCK, *Naval Research Laboratory.*—He^3 nuclei accelerated by the N.R.L. 2 Mev Van de Graaff generators have been used to investigate the angular distributions of the four highest energy proton groups from the $Be^9(He^3,p)B^{11}$ reaction.[1] These measurements were made with a multiplate reaction camera having 200 micron *C2* nuclear emulsions placed at 5° intervals over the angular region extending from 5° to 170°. All the angular distributions were observed to have an extreme in the neighborhood of 70° and exhibit a lack of symmetry about 90°.

[1] Holmgren, Bullock, and Kunz, Phys. Rev. **100**, 436 (1955).

P7. Electrostatic Analysis of Nuclear Reaction Energies, IV. REN CHIBA, R. A. DOUGLAS, J. W. BROER, D. F. HERRING, AND E. A. SILVERSTEIN, *University of Wisconsin.**—Cylindrical and spherical electrostatic analyzers have been used to measure the energies of incident and outgoing charged particles as described earlier. Stable targets of deuterium and nitrogen were formed by gettering of these gases by titanium in an Evapor-ion pump. These targets (heated) were used for the $D(d,t)H^1$ and $D(d,He^3)n$ reactions; $N^{14}(d,p)N^{15*}$ and $N^{14}(d,\alpha)C^{12*}$ reactions. Also measured was the $B^{10}(\alpha,d)C^{12}$ reaction. Preliminary calculations of Q values are in agreement with earlier measurements or mass values. Further calculations and error evaluations are underway. The 9.61-Mev C^{12} level had an experimental width of ~40 kev, indicating alpha emission. Therefore J and parity are restricted to 0^+, 1^-, 2^+, 3^-. (For 4^+ the reduced width is approximately twice the Wigner limit.)

* Work supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

P8. Analysis of $C^{13}+d$ Reactions. M. T. MCELLISTREM,* *University of Wisconsin.*†—Previously reported differential cross section for $C^{13}(d,d)C^{13}$, $C^{13}(d,p)C^{13}$ and $C^{13}(d,p)C^{13*}$, ($E_x(C^{13})=3.09$ Mev) have been analyzed to display the stripping and compound nuclear contributions. Dispersion formalism has been used to fit the elastic scattering data at two "isolated" resonances. One at $E_d=2.502$ Mev ($E_x(N^{15})=12.41$ Mev) is assigned spin and parity of 4^-. Another at $E_d=2.735$ Mev ($E_x(N^{15})=12.60$ Mev) is assigned 3^+. These assignments also agree qualtitatively with the (d,p) data. $C^{13}(d,p)$ and (d,n) cross sections have been further analyzed by the method of Bowcock,[1] which separates the data into the stripping amplitude described by Butler and all nonstripping components. The reduced widths are extracted from the stripping amplitude. The widths of C^{13} and N^{15} are found to be equal and have the value $(0.09\pm0.035)(3\hbar^2/2\mu a)$. The width of the 3.09-Mev level is found to be $(0.27)(3\hbar^2/2\mu a)$. This value is in reasonable agreement with the width of the mirror level in N^{15}.

* Now at Indiana University.
† Work supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] J. E. Bowcock, Proc. Phys. Soc. (London) **68A**, 512 (1955).

P9. $C^{14}+d$ Reactions. R. A. DOUGLAS, J. W. BROER, AND REN CHIBA, *University of Wisconsin.**—Uniform thin C^{14} targets on 2500 A nickel backings were prepared in a discharge tube containing acetylene (enriched to 28.8% C^{14}). Monoergic ($\pm0.05\%$) deuterons selected by a 90° cylindrical electrostatic analyzer were used to bombard the targets. Reaction products at 135° were measured with the spherical electrostatic analyzer (0.24% resolution). For $C^{14}(d,\alpha)B^{12}$ a $Q=+0.36_4$ Mev was observed (preliminary calculation). No protons (<0.05 mb/sterad for $E_d=1.8$, 1.9, and 2.1 Mev) from $C^{14}(d,p)C^{15}$ could be found corresponding to the reported $Q=+0.12$ Mev. However, an intense proton group corresponding to a $Q=-0.96$ Mev for $C^{14}(d,p)C^{15}$ was identified. The 2.4-sec C^{15} activity was observed (NaI scintillator) to decrease sharply to near background as the deuteron energy decreased to 1.3 Mev. (For our $Q=-0.96$, $E_{thres}=\sim1.1$ Mev.) No appreciable intensity of high energy ($\sim5-10$ Mev) beta activity corresponding to the ground-state transition was observable. Aluminum absorbers of 2.5 cm thickness attenuated the 2.4-sec activity only by 25% indicating the presence of high-energy gamma rays. Presumably most (if not all) of the beta transitions are to excited states of N^{15}.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

P10. Isotopic Spin-Selection Rule Violation in $O^{16}(d,\alpha)N^{14*}$.† C. P. BROWNE, *M.I.T.*—A group of alpha particles from the $O^{16}(d,\alpha)N^{14*}$ reaction, leading to the first excited state, has been observed. Previous experiments indicate that this state has $T=1$.[1] Many attempts to observe the present reaction at various energies from 2 to 19 Mev have failed[2] as they should if isotopic spin is conserved. The yields of this forbidden alpha group and of the alpha groups leading to the ground state and

second excited state have been measured as a function of bombarding energy from 5.50 to 7.5 Mev in 250-kev steps. The angle of observation was 30°. These groups have also been measured at various other angles at 7.0 Mev. A resonance is observed at about 7.0 Mev. At this energy, the intensity of the forbidden group rises somewhat, while the intensity of the two allowed groups drops sharply. The intensity ratios of the first excited-state group to the ground-state and second excited-state groups reach 14 and 48%, respectively. The M.I.T. broad-range spectrograph was used to separate the alpha groups, and nuclear plates and a scintillation counter were used to record the particles. The relative intensities with energy change are thought to be good to about 15%, while the intensity ratios of the three groups are good to 5%.

† This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bockelman, Browne, Sperduto, and Buechner, Phys. Rev. **92**, 665 (1953).
[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

P11. Excited States of O^{16} from Proton Bombardment of N^{15}.* R. R. Carlson and S. Bashkin, *State University of Iowa.*—Natural nitrogen gas targets and silver nitrate targets, with N^{15} content enriched to 61%, were bombarded with protons of energy from 0.8 Mev to 3.2 Mev. Resonances for the production of 4.4-Mev gamma rays from the $N^{15}(p,\alpha\gamma)C^{12}$ reaction were detected with a NaI(Tl) crystal. The resonance at 1660±20 kev bombarding energy[1] was found to have a width of 95±10 kev. Previously unobserved resonances were found at bombarding energies of 1990±20 kev and 3000±30 kev with widths of <30 kev and 90±20 kev, respectively. These resonances correspond to excited states in O^{16} at 13.98 Mev and 14.92 Mev, respectively. The present experiment gave no evidence of the state in O^{16} at 14.2 Mev which has been reported on the basis of the photo disintegration[2] of O^{16}.

* Supported in part by the U. S. Atomic Energy Commission.
[1] A. A. Kraus, Phys. Rev. **94**, 975 (1954).
[2] P. Stoll, Helv. Phys. Acta **27**, 395 (1954).

P12. The Inelastic Scattering of Protons from F^{19}.* B. J. Toppel, D. H. Wilkinson,† and D. E. Alburger, *Brookhaven National Laboratory.*—The gamma radiation following inelastic proton scattering from F^{19} has been observed using 2.4- to 4.1-Mev protons from the BNL research Van de Graaff. Gamma rays of energies 1.238±0.010 Mev and 1.350±0.010 Mev are observed in the singles NaI(Tl) spectrum using 3.0-Mev protons. The angular distributions of these gamma rays show anisotropies of +29% and −29%, respectively. Three crystal pair spectrometer measurements at 3.0 Mev and 3.5 Mev indicate that a 1.449±0.010 Mev gamma ray is also present. Coincidence measurements at 3.0 Mev show that gamma rays of energies 1.233±0.010 Mev and 1.346±0.010 Mev are in prompt coincidence with 109-kev radiation while a 1.354±0.010 Mev gamma ray is in delayed coincidence with 197-kev radiation. In addition the 109-kev radiation is found to have the same energy when seen in singles or in coincidence with 1.24-Mev gamma rays. These observations imply states in F^{19} at 1.342±0.010 Mev, 1.452±0.010 Mev, and 1.551±0.010 Mev. The observed relative gamma-ray intensities show that the 1.24-Mev radiation originates mainly from the 1.34-Mev state and that the 1.34-Mev state exhibits less than an 8% branch to the $J=5/2+$ level at 197 kev. These observations together with the observed nonisotropicity of the 1.24 Mev radiation indicate an assignment $J=3/2$ for the 1.34 state.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Cavendish Laboratory, Cambridge, England.

P13. The Pickup Reactions $F^{19}(n,d)O^{18}$.* F. L. Ribe, *Los Alamos Scientific Laboratory.*—Thin targets of Teflon were bombarded with 14.1-Mev neutrons, and reaction deuterons were detected with a proportional counter-scintillator telescope at various angles. A strong deuteron group corresponding to the ground state of O^{18} and a weak group corresponding to an excited state at 1.9±0.1 Mev were observed, and their differential cross sections were measured for laboratory angles between zero and 80 degrees. No further excited-state groups were observed for excitations up to three Mev. Above three Mev the deuteron groups were not resolved. The ground-state differential cross section is well fitted by a Butler curve with $l_p=0$, while no clear pickup structure is indicated for the 1.9-Mev excited state. Using the Butler formula to extract kinematical effects, one obtains the following values and upper limits for the dimensionless reduced-width factors θ_p^2 for the $F^{19}\rightarrow O^{18}$ transitions: Ground state—$l_p=0$: $\theta_p^2=0.036$. Relative $\theta_p^2=1.00$. 1.9-Mev level—$l_p=0$, 1, 2: $\theta_p^2\leq 0.0015$, 0.0068, 0.031. Relative $\theta_p^2\leq 0.041$, 0.19, 0.87. *S*-wave pickup to the excited state thus appears to be forbidden. A separate search gave no indication of ground-state protons from the reaction $F^{19}(n,p)O^{19}$.

* Work done under the auspices of the U. S. Atomic Energy Commission.

P14. A 5.3-Mev Energy Level in Mg^{24} Following the Decay of Na^{24}. F. M. Tomnovec and C. S. Cook, *U. S. Naval Radiological Defense Laboratory.*—Capture gamma rays from the reaction $Na^{23}(p,\gamma)Mg^{24}$ have led to the assignment[1] of an energy level at 5.23 Mev in Mg^{24}. The spins and parities tentatively assigned to this energy level make it appear that Na^{24} should be able to decay to this level. Observation on the high-energy gamma radiations of Na^{24} using a 4 in. diameter by 4 in thick NaI(Tl) crystal scintillation spectrometer has shown radiation at 3.9 and 5.3 Mev, confirming the existence of this level in the decay of Na^{24}. The 3.9-Mev radiation,[2] according to this scheme, follows a transition from the 5.3-Mev level to the 1.38-Mev level in Mg^{24}.

[1] J. O. Newton, Phys. Rev. **96**, 241 (1954).
[2] Beghian, Bishop, and Halban, Phys. Rev. **83**, 186 (1951).

P15. Lifetimes of First Excited States of Al^{28} and B^{10}. J. C. Severiens and S. S. Hanna, *Johns Hopkins University.**—A modification of the Thirion-Telegdi recoil method,[1] incorporating coincidence counting, has been used to determine the lifetimes of states in nuclear reactions. In the reaction $Al^{27}(d,p)Al^{28*}(32\text{ kev})Al^{28}$, forward moving recoils are obtained by observing only coincidences between gamma rays and protons emitted (approximately) antiparallel to the deuteron beam. The gamma counter is at 0° to the beam, at a distance approximately $2d$, where d is the distance traveled by a recoil during its mean life. A recoil "stopper" is placed between target and counter and the coincidence yield measured as a function of stopper position. In effect, one measures the change in solid angle produced by mechanically controlling the range of the recoils. The method provides a beam of excited nuclei produced in a unique manner and with a known spatial distribution. In the reaction $Be^9(d,n)B^{10*}(\gamma)B^{10}$ the 2.86-Mev gamma was used to tag the 0.72-Mev gamma, the recoil angular distribution being obtained from the known neutron distribution. The effect of target thickness was investigated with targets of different thickness. Lifetimes of $(2.7\pm0.03)\times10^{-9}$ and $(9.5\pm2.0\times10^{-10}$ sec were obtained for Al^{28*} and B^{10*}, respectively. The method gave a negative result for the 477-kev state in Li^7.

* Assisted by a contract with the U. S. Atomic Energy Commission.
[1] J. Thirion and V. L. Telegdi, Phys. Rev. **92**, 1253 (1953).

SATURDAY MORNING AT 9:30

Mandel Hall

(R. T. BIRGE presiding)

Invited Papers on Bubble-Chamber Experiments

Q1. Hydrogen Bubble-Chamber Design and Experiments. LUIS W. ALVAREZ, *University of California, Berkeley.* (30 min.)

Q2. Pion-Proton Scattering Observed with a Liquid-Hydrogen Bubble-Chamber. D. E. NAGLE, *University of Chicago.* (30 min.)

Mesons

Q3. Meson Production in *n-p* Collisions by Cosmotron-Produced Neutrons with Energies up to 1.5 Bev.* W. A. WALLENMEYER, *Purdue University* (introduced by C. Y. CHANG).—This is a continuation at lower incident neutron energies of an experiment previously done by the Brookhaven Cloud Chamber Group.[1] 158 of about 210 three-prong events obtained from collisions between neutrons, with energies up to 1.5 Bev, and protons in a hydrogen-filled cloud chamber, have been analyzed. These events have been classified as resulting from the reactions $n+p\rightarrow p+p+\pi^-$, $\rightarrow p+p+\pi^-+\pi^0$, and $\rightarrow p+n+\pi^++\pi^-$ in the ratio 40:0:6 below 1 Bev and in the ratio 41:12:7: above 1 Bev. The observed ratio of double to single meson production is again more than 20 times higher than the ratio predicted from Fermi's statistical theory. In the center-of-mass system, in the reaction $\rightarrow p+p+\pi^-$, the protons are very strongly peaked in the forward and backward directions and have very strong tendencies toward opposite directions. In cms, in the reaction $\rightarrow p+p+\pi^++\pi^-$; p and π^+, n and π^-, and also p and n all show a very definite tendency to be emitted in opposite directions to each other. The tendency of p and π^+ to be emitted backward and n and π^- to be emitted forward which was observed in the previous experiment does not show up here.

* Performed under the auspices of the U. S. Atomic Energy Commission at Brookhaven National Laboratory and partially supported by the Purdue Research Foundation.

[1] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **95**, 1026 (1954).

Q4. Photoproduction of π^0 Mesons in Helium.* E. L. GOLDWASSER AND L. J. KOESTER, JR., *University of Illinois.*—An experiment has been performed to compare the energy dependence, from threshold to 300 Mev, of π^0 photoproduction in helium with that in hydrogen. The neutral pions were detected by counting γ rays emitted at a laboratory angle of 84°. The photon difference method was used to show that a cross section maximum occurs in helium at a photon energy near 280 Mev. This is much lower than the 325-Mev energy of the hydrogen peak. The "elastic" process, $h\nu+\mathrm{He}^4\rightarrow\pi^0+\mathrm{He}^4$, has been shown to play an important role in the photoproduction of π^0 mesons from helium.[1,2] It seems probable that the neutral pions produced both in the elastic and inelastic processes stem basically from the strong single nucleon-pion interaction in the 3/2, 3/2 state. The observed shift in energy may be qualitatively explained under the assumption that the production process is predominantly elastic. The inelastic process, as a result of the 20-Mev He binding energy which must be supplied, should give to a shift in the opposite direction. Analysis to obtain absolute cross sections is in progress.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Goldwasser, Koester, and Mills Phys. Rev. **95**, 1692 (1955).

[2] G. DeSaussure and L. S. Osborne, Phys. Rev. **99**, 843 (1955).

Q5. Scattering of 38-Mev Positive Pions in Hydrogen.* A. M. SACHS, H. WINICK, AND B. A. WOOTEN, *Columbia University.*—Measurements have been made of the differential cross sections of 38±7 Mev positive pions scattered in hydrogen at several angles. In preliminary runs the 60-Mev external pion beam from the Nevis cyclotron, after being analyzed in a double-focusing magnet, was slowed down in LiH and defined by two scintillation counters. After scattering in a liquid hydrogen target,[1] the pions were detected by two 3 in. ×6 in.×¼ in. counters, the second of which was 14½ in. from the target. In addition, the mass and energy of the scattered particles were identified by photographing the pulse heights in the detecting counters and a 4 in.×7 in. liquid counter 5 inches thick, in which the pions were brought to rest. In the center-of-mass system, $d\sigma/d\Omega=0.28\pm0.20$ mb/sterad at 69 deg, $d\sigma/d\Omega=0.86\pm0.15$ mb/sterad at 100 deg, and $d\sigma/d\Omega=1.48\pm0.19$ mb/sterad at 122 deg. More recently, a magnetic channel has made available lower energy external beams of positive pions. Experiments are now in progress with better energy resolution (38±3 Mev) and improved pulse-height counters including a plastic scintillator 5½ in.×8½ in.×6 in. thick.

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Bodansky, Sachs, and Steinberger, Phys. Rev. **93**, 1367 (1954).

Q6. Positive Pion Scattering by Hydrogen at 260, 300, and 400 Mev.* R. S. MARGULIES, *Brookhaven National Laboratory.*—The Brookhaven six-foot diffusion chamber has been used at the Cosmotron to study elastic π^+-p scattering. With an assumed total cross section of 110 mb[1] at 260 Mev, analysis of 100 scatterings yields the least squares angular distribution $d\sigma/d\Omega=\lambda^2(0.680+0.540x+3.007x^2)$, where $x=\cos\theta$ (c.m.). This can be fitted with the phase shifts $\alpha_3=-12°$, $\alpha_{31}=-11°$, $\alpha_{33}=116°$. At 300 Mev, assuming a total cross section of 75 mb,[1] the angular distribution of 151 scatterings is $d\sigma/d\Omega=\lambda^2(0.662+0.792x+2.101x^2)$, which can be fitted with the phase shifts $\alpha_3=-17°$, $\alpha_{31}=-4°$, $\alpha_{33}=127°$. At 400 Mev, partially completed analysis, based on the 47 scattering angles so far measured, and a total cross section of 35 mb,[1] yields the angular distribution $d\sigma/d\Omega=\lambda^2(-0.03-0.60x+2.78x^2+3.07x^3)$. If it is assumed that the large forward peak is partially due to D-waves, then the distribution can be fitted by the phase shifts $\alpha_3=\alpha_{31}=-22°$, $\alpha_{33}=158°$, $\alpha(D_{3/2}=-22°$, $\alpha(D_{5/2})=0$. However, other combinations of D-wave phase shifts are possible.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] S. J. Lindenbaum and L. C. L. Yuan, Phys. Rev. **100**, 306 (1955).

SATURDAY MORNING AT 9:15

Eckhart 133

(A. W. LAWSON presiding)

General Solid-State Physics

R1. Angular Correlation of Annihilation Radiation in Superconducting Lead. R. STUMP, *University of Kansas.*—The angular correlation of annihilation radiation from positrons stopped in a solid gives a measurement of electron momentum in the solid. A measurement of the correlation in superconducting lead was made to determine whether any change in momentum of the annihilating electrons occurs in the superconducting state. Angular correlation measurements were made on radiation from positrons stopped in lead at 300°K, 77°K, and 4°K; in each case with magnetic fields of 100 and 1200 gauss. Within the limits of accuracy of the experiment, the angular correlation is the same in each of the six cases. The electron momentum distribution is in agreement with that predicted assuming four free electrons per atom in an ideal Fermi gas at 0°K, plus a high velocity tail resulting from occasional annihilation with more tightly bound electrons. Work with other superconductors is being continued.

R2. Hall Effect and Magnetoresistance of Bi Single Crystals at He Temperatures.* R. A. CONNELL AND J. A. MARCUS, *Northwestern University.*—Measurements of the Hall coefficient and magnetoresistance have been made on single crystals grown from unpurified Cerro de Pasco bismuth. Using a modified Schubnikov technique, rods of 2 mm square cross section were obtained. Three appropriately seeded crystals of this geometry were sufficient for the examination of the six principal crystallographic oreintations. At 42°K the Hall coefficient showed pronounced de Haas-van Alphen oscillations, with periods ranging from 2.3×10^{-5} gauss^{-1} to 9.6×10^{-5} gauss^{-1}. The oscillations occurred about an approximately zero mean value, corresponding more closely to the original work of Gerritsen[1] than to the recent findings[1,2] where the oscillations were superposed on a large negative term. This difference is believed to be due to impurities, the samples having an average residual resistance ratio $\rho_{4.2°K}/\rho_{273°K} \simeq 8\times10^{-3}$. (An attempt at zone refining is being made.) The magnetoresistance was found to be roughly proportional to $H^{1.7}$, with a small oscillating term superposed. Work at lower temperatures is now in progress.

* Supported by the National Science Foundation.
[1] L. C. Brodie, Phys. Rev. **93**, 935(A) (1954).
[2] W. C. Overton and T. G. Berlincourt, Phys. Rev. **99**, 1165 (1955).

R3. Thermal Diffusivity of Uranium from Room Temperature to 1000°C.* P. H. SIDLES, *Iowa State College.*—The thermal diffusivity of uranium has been measured in the temperature range 25–1000°C. In this range uranium transforms from an orthorhombic α phase to a complex β phase at 668°C and to a cubic γ phase at 770°C. The procedure followed was to α-anneal and measure the thermal diffusivity in the α temperature range; then β-anneal and measure thermal diffusivity in the β region, transform back to the α phase, anneal and again measure the thermal diffusivity in the α region. Small segments were periodically removed from the sample for grain size determinations. The β treatment caused a large increase in grain size and a 5–10% decrease in the α region thermal diffusivity. The sample was then γ-annealed and thermal diffusivity measurements made in all three phases. The α phase grain size and thermal diffusivity after the γ treatment were not appreciably different from those after β the treatment. Thermal conductivity (K) can be calculated using the relation $K=kcd$ where k is thermal diffusivity, c is specific heat, and d is density. The thermal conductivity of uranium, obtained in this manner, will be reported.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

R4. Electrical Conduction in Plexiglas.* RAYMOND J. MUNICK, *Argonne National Laboratory.*—The electric current from one-millimeter thick specimens of Plexiglas was studied as a function of time, temperature, and voltage. The time-dependent part, which contributes to the polarization of the dielectric, showed a slight but definite departure from the t^{-n} time decay typical of solid insulators.[1] Also, it showed a relatively small change with temperature compared to the exponential increase of the steady part, or conduction current, from 25 to 75°C. Thermal activation energies of 1.4 to 1.5 electron volts were found for the conductivity, which compare reasonably well with the value of 1.6 ev reported for unplasticized Perspex,[2] which like Plexiglas is a polymer of methyl methacrylate. The room temperature conductivities were found to be around 10^{-19} mhos per cm. The conduction currents obtained at 60 and 75°C were approximately proportional to voltage for values from 315 to 3125.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. F. Manning and M. E. Bell, Revs. Modern Phys. **12**, 215 (1940).
[2] J. F. Fowler and F. T. Farmer, Nature **175**, 516 (1955).

R5. Young's Modulus of Gold-Nickel Alloys. J. SIVERTSEN AND C. WERT, *University of Illinois.*—At high temperatures alloys of gold and nickel are solid solutions at all compositions, but at low temperatures, the stable alloy (over most of the composition range) is a mixture of a gold rich phase and a nickel rich phase. By quenching an alloy from the high-temperature region to room temperature, one can regain the solid solution characteristic of the high-temperature phase. Quenched solutions of intermediate composition decompose into a two-phase mixture when the material is annealed at slightly elevated temperatures. Changes in a number of physical properties (e.g., electrical resistance and microstructure) have been observed to accompany this phase separation. Changes in internal friction of these alloys have also been observed during this annealing, but they precede the actual phase separation as it is observed by other means. The mechanism responsible for these changes in internal friction is not known. It seemed desirable to determine whether this effect might be correlated with changes in some other physical property as well. We have measured changes in Young's modulus during the annealing of a 30% Ni alloy, and we do find an increase in the modulus occurring concurrently with changes in the internal friction.

R6. Effect of V_2O_5 on Spinel Formation.* D. M. GRIMES AND J. W. KUIPER.—Vanadium pentoxide has been found to act as a mineralizer in lowering the temperature necessary for densification and in some cases spinel formation. This has been observed for Fe_2O_3 alone and for Fe_2O_3 plus Ni^{2+}, Zn^{2+}, Li^{1+}, Cd^{2+}, Mn^{2+}, Co^{2+}, or Mg^{2+}. The necessary formation temperature is increased for Fe_2O_3 plus Cu^{2+}, Mn^{4+}, or Co^{3+}, and is nearly unaffected for Fe_2O_3 plus Ca^{2+} or Ba^{2+}. This gives resulting magnetic properties somewhat different from the usual

by eliminating the side effects of high firing temperature, such as ferrous iron.

* Grimes, Thomassen, Jefferson, and Kothary, J. Chem. Phys. (to be published).

R7. A Neutron Diffraction Study of VD_x. B. W. ROBERTS, *General Electric Research Laboratory.*—A sample of vanadium deuteride near the composition V_4D_3 has been studied by x-ray and neutron diffraction. At room temperature, x-rays disclose a swollen b.c.c. arrangement of the vanadium atoms ($a_0 = 3.14_9$ A) with no evidence for the deuterium locations while neutron diffraction traces yield a single diffraction peak at the 110 position. No peaks are observed at the 200, 211, or 220 positions, however, a very broad diffuse maximum is centered to a low angle of the 110 reflection. Due to the very low coherent cross section of vanadium and the favorable cross section of deuterium the neutron intensity observed in the peaks is almost entirely due to the deuterium. Neutron data taken at liquid nitrogen temperature show no evidence of a diffuse maximum. Twenty-two reflections are observed which index with a primitive cubic cell with a_0 equal 6.30 A. This cell edge is twice the edge of the b.c.c. vanadium lattice observed at liquid nitrogen temperature with x-rays and therefore requires an ordering of the deuteriums in a cell eight times the volume of the required vanadium cell. The transformation from the "ordered" to "disordered" phases occurs at $207° \pm 10°$K.

R8. On the Crystal Structure of the Solid Rare Gases.* R. U. AYRES AND R. H. TREDGOLD, *University of Maryland* (Introduced by R. D. Myers).—All the rare gases with the exception of helium are observed to solidify in the face-centered cubic structure. Previous theoretical work, however, has predicted that the close packed hexagonal structure should be energetically favorable. A semiclassical model has been developed which allows one to take account of the overlapping of the electronic charge clouds of neighboring atoms, and this has been applied to both two-body and three-body interactions In the case of pure dipole interactions the results degenerate to those previously obtained by Axilrod.[1] When the additional effect of overlap is calculated for tripole-dipole interactions a new angular dependence is derived. When the third-order terms are summed for the two lattices a significant difference in the right direction is obtained. Indeed for reasonable values of the parameters of the model the difference more than counteracts the unfavorable difference arising from the second-order terms previously obtained by other authors.

* Supported by the United States Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] B. M. Axilrod, J. Chem. Phys. 19, 719 (1951).

R9. Soft X-Ray Emission Spectrum of Germanium.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—The emission spectrum of a germanium target was investigated in the spectral region extending from 60 A to 600 A. The germanium surface was formed by evapoartion in the x-ray tube. The deposition was carried out with the target surface at room temperature and also at 400°C in an attempt to observe changes in the emission spectrum which could arise from differences existing in the structure of the target layer. No such changes were observed. Two bands whose edges lie at 102 A and 103.5 A have been detected. These are tentatively identified as transitions from the valence levels to the M_2 and M_3 states, respectively.[1] The emission lines corresponding to the $K \rightarrow M_{4,5}$ transitions have been observed previously,[2] indicating that the $M_{4,5}$ levels fall below the valence band. Thus, in the wavelength range of the present investigation, one could expect to find the $M_{4,5} \rightarrow$valence emission band. Examination of the spectrograms does not reveal the presence of this band.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] J. C. Slater, Phys. Rev. 98, 1039 (1955).
[2] J. A. Bearden and C. H. Shaw, Phys. Rev. 48, 18 (1935).

R10. Brillouin Zone Studies. V. Thermoelectric Power of Dilute Magnesium Alloys. E. W. KAMMER, E. I. SALKOVITZ, AND A. I. SCHINDLER, *U. S. Naval Research Laboratory.*—At room temperature the elements Li, Al, Ag, Cd, In, Sn, Tl, and Pb form terminal substitutional solid solutions in Mg. Salkovitz and Schindler[1] have suggested that Brillouin zone overlap in these systems may be studied by observing various transport phenomena as a function of alloying additions. Such a study has now been made on the effect of these alloying additions upon the thermoelectric power. It is found that a reversal in electrical polarity occurs at low concentrations for additions of the tri- or tetra-valent additions near the region of overlap. The ratio of thermoelectric power to atomic percent impurity element is a cyclic function of atomic number. For concentrations greater than those characterized by initial overlap conditions these cycles are in phase with the valence series of the periodic table. Resistivity and Hall effect measurements[1,2] on these alloys are compared for correlations of behavior at the Brillouin zone overlap concentrations.

[1] E. I. Salkovitz and A. I. Schindler, Phyc. Rev. 91, 234, 1320 (1953).
[2] Salkovitz, Pasternak, and Schindler, Phys. Rev. 98, 271 (1955).

R11. Perturbation Calculation of the Volume Exclusion Effect.* IRA JACOBS, *Bell Telephone Laboratories.*—It is desired to determine the distribution of configurations of flexible long-chain molecules considering the fact that no two parts of the chain can occupy the same position in space. Experiments[1] indicate that the mean-square chain extension increases more rapidly than the number of links in the chain N, which cannot be explained by any theory that takes account only of correlations between neighboring elements of the chain. It is shown that for $N \approx 40$ to 400, the first-order theory of James[2] predicts that the mean-square extension increases as $N^{1.35}$ in good agreement with experimental[1] and Monte Carlo[3] results. A second-order calculation gives significant corrections for large N, but there is an inherent limitation of the perturbation approach due to the fact that the relative number of allowable configurations decreases exponentially with N. Sufficient computation can extend the validity of the results to larger N, but no statements on limiting behavior can be made.

* Taken from part of a dissertation submitted to Purdue University, June, 1955.
[1] Schultz, Cantow, and Meyerhoff, J. Polymer Sci. 10, 79 (1953).
[2] H. M. James, J. Chem. Phys. 21, 1628 (1953).
[3] M. N. Rosenbluth and A. W. Rosenbluth, J. Chem. Phys. 23, 356 (1955).

R12. Time Dependence of Mechanical Breakdown Phenomena. BERNARD D. COLEMAN, *E. I. du Pont de Nemours and Company.*—A phenomenological theory of the time dependence of mechanical breakdown phenomena is presented which yields general expressions for the distribution of breaking times in ensembles of filaments which have been subjected to arbitrary loading histories. The theory is applicable to discussions of the creep failure of polymeric solids under uniaxial tensile stresses. Several articles have appeared in the literature attempting to explain observed tensile strength distributions in terms of static models which can be treated by the methods of extreme value statistics. The present treatment differs from the extreme value theories, in that its *a priori* assumptions account for the time dependence of mechanical strength measurements. This permits a calculation of the dependence of the observed tensile strength on both the sample size and the rate of loading. The distribution of lifetimes of an ensemble of fibers is discussed for three special stress histories: dead loads, loads increasing linearly with time, and sinusoidal loads. Experiments involving drawn 66 nylon monofilament yarn are cited to illustrate how the parameters which describe the average lifetime under dead load behavior of a yarn may be used to calculate its tensile strength distribution when measured with a constant rate of loading apparatus.

R13. Use of the Field Emission Microscope for Investigating Surface Conditions on an Alloy.* L. A. D'ASARO,† *Cornell University.*—An alloy of a few percent of zirconium in molybdenum is used as an emitter in a field emission microscope. When the cleaned alloy surface is heated, diffusion of zirconium from the interior onto the surface is observed. This zirconium is always found on or near the 100 plane. After flashing to 2400°K, the rate of diffusion increases. This increase is interpreted as resulting from an increased vacancy concentration produced within the alloy by the flashing. Activation energies for diffusion of zirconium from the interior onto the surface can be found. A maximum in the quantity of zirconium present on the surface as a function of heating time is interpreted on the basis of the Wagner-Johnson vacancy theory of diffusion. Under certain conditions small parallelogram shaped patterns are seen on the 100 plane. The work function of the sources of these patterns, the field at the surface of the sources, and the size of the sources are determined by a method of matching the Fowler-Nordheim equation to an experimental plot of field emission current *versus* potential.

* This research was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
† Now at Bell Telephone Laboratories.

SATURDAY MORNING AT 9:30

Cobb 110

(E. L. HILL presiding)

Invited Papers

S1. Recent Developments in the Theory of Atomic Spectra. FRITZ ROHRLICH, *State University of Iowa.* (30 min.)

S2. The Impact of Electronic Digital Computers on Molecular Quantum-Mechanical Calculations. C. C. J. ROOTHAAN, *University of Chicago.* (30 min.)

S3. The Measurement of Magnetic Moments of Excited Nuclear States. R. M. STEFFEN, *Purdue University.* (30 min.)

SATURDAY MORNING AT 9:15

Kent 106

(G. C. DANIELSON presiding)

Semiconductors, II

T1. Magnetoresistance and Mobility of Germanium-Silicon Alloys. M. GLICKSMAN, *RCA Laboratories.*—The magnetoresistance and Hall mobility of germanium-rich and silicon-rich *n*-type single crystals. The observed variation of the magnetoresistance asymmetry as a function of alloy composition is interpreted in terms of a band structure model proposed by Herman[1] to explain the change in band gap with composition.[2] A competition between [111] and [100] ellipsoidal conduction minima occurs for alloys with 11–15% silicon content. The two sets of minima are at the same energy for crystals containing about 15% silicon. In addition, the mobility measurements combined with the magnetoresistance give information on the variation of the shape of the conduction minima with composition. For germanium-rich alloys the ratio of the longitudinal to transverse effective masses remains essentially constant for crystals containing up to 7% silicon and appears to decrease in the range 7–10% silicon. Measurements of silicon-rich alloys indicate a decrease in the effective mass ratio for alloys of only 2–3% germanium content.

[1] F. Herman, Phys. Rev. **95**, 847 (1954).
[2] E. R. Johnson and S. M. Christian, Phys. Rev. **95**, 560 (1954).

T2. Hall Effect and Magnetoresistance in *n*-Type Germanium.* W. M. BULLIS† AND W. E. KRAG, *Lincoln Laboratory.*—Measurements of the Hall and magnetoresistance coefficients of *n*-type germanium have been made on a number of single crystals with room temperature resistivities from 0.01 to 25 ohm-cm. It is shown that if the electron mobility is not strongly dependent on the temperature (or on the energy of the electron) the experimental results may be explained by calculations based on an energy independent scattering time. Although the agreement between these theoretical calculations and experiment is not exact, the symmetry properties, which are dependent on the band structure, are accurately matched. In addition, particular attention is focused on the limits of these coefficients for both high and low magnetic fields. These limits may be most easily compared with theoretical calculations based on more complicated scattering times, for example the energy dependent scattering time $\tau = l\epsilon^p$, where l is independent of the energy ϵ.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
† On educational leave from the Diamond Ordnance Fuze Laboratories, Washington, D. C.

T3. Copper in Germanium: Recombination Center and Trapping Center. B. J. WYLUDA AND R. G. SHULMAN, *Bell Telephone Laboratories.*—The time dependent photoconductivity of copper doped *n*-type and *p*-type germanium bridges has been measured between 130°K and 293°K. Temporary hole traps[1] were found in the *n*-type samples at the lower temperatures but no traps were observed in the *p*-type. Trap concentrations agreed with the density of copper atoms to within a factor of two and were at least 100 times higher than in undoped crystals. The trapping levels are 0.2 ev above the valence band;

the capture cross section for holes, σ_p, is 10^{-16} cm^2 and independent of temperature while the capture cross section for electrons, σ_n, is temperature dependent with an activation energy greater than 0.1 ev.[2] As a result of this temperature dependence of σ_n the 0.2 ev copper level changes from a recombination center[3] at room temperature to a hole trap at lower temperatures.

[1] J. R. Haynes and J. A. Hornbeck, Phys. Rev. **90**, 152 (1953); H. Y. Fan, Phys. Rev. **92**, 1424 (1953).
[2] R. M. Baum and J. F. Battey, Phys. Rev. **98**, 923 (1955).
[3] Burton *et al.*, J. Phys. Chem., **57**, 102 (1953).

T4. Measurement of Bulk and Surface Recombination by Photoconductance. H. M. Bath and M. Cutler, *Hughes Aircraft Company.*—A refinement has been made in the theory for photoconductivity, which takes into account both surface and bulk recombination. There are two interesting cases: wavelengths that are absorbed completely at the surface, and wavelengths absorbed nearly uniformly throughout the sample. The dependence of the conductance on the two types of recombination differs in the two cases, so that one can, under proper circumstances, measure both surface recombination velocity s and bulk lifetime τ in the same sample. Experimental procedures for making these measurements have been devised and the method was proved with germanium. A further advantage for the measurement with surface absorbed light is that one can measure accurately large values of s. This cannot be done with most other standard methods except the photoelectromagnetic method, which is based on the same physical situation. The effects of sandblasting and lapping germanium surfaces were measured; the former gave s of 1–2×10^5 cm/sec, and the latter had values of s of 5–10×10^5 cm/sec. Lapped surfaces showed some evidence of healing.

T5. Recombination Radiation from Silicon. J. R. Haynes, *Bell Telephone Laboratories.*—Radiation caused by the recombination of excess electrons and holes in silicon has been reported by Haynes and Briggs.[1] Recent experiments indicate that this radiation is due to indirect transitions of electrons from the conduction band minima to the valence band with phonon cooperation (indirect intrinsic recombination radiation). Additional radiation is found at 77°K which is structure sensitive. This radiation is shown to be produced by the recombination of excess carriers with unionized donor and acceptor centers (extrinsic recombination radiation). Differences between the photon energies associated with the maximum photon emission of intrinsic and extrinsic radiation are qualitatively in accord with accepted values of ionization energies of the donor and acceptor impurities introduced in the silicon crystal growing process.

[1] J. R Haynes and H. B. Briggs, Phys. Rev. **86**, 647 (1952).

T6. The Field Effect in Silicon. S. Penman and W. L. Brown, *Bell Telephone Laboratories.*—Field effect measurements were made on silicon using large ac electric fields (peak $\sim6\times10^5$ volt/cm). The samples were first dried by heating in a desiccated nitrogen atmosphere and then the field effect studied as a function of temperature and various gaseous ambients. Oxygen tends to change the surface potential in the negative direction and nitrogen in the positive direction. Effective mobilities were found to be about an order of magnitude smaller than bulk carrier mobilities, in contrast to the results reported by Low.[1] The observation of the minimum of conductance permits the determination of the surface charge as a function of the position of the Fermi level at the surface.[2] The surface state distribution is found to be more uniform than in the germanium case with an apparent density at the center of the energy gap of about 10^{13} states/cm^2 volt. Water vapor is responsible for a substantial increase in the apparent surface state density, often to such an extent that the effective mobility is reduced below the limit of our observation (≈1 cm^2/volt sec).

[1] G. G. C. Low, Proc. Phys. Soc. (London) **B68**, 10 (1955).
[2] W. L. Brown, Phys. Rev. **98**, 1565 (1955).

T7. Thermal Defects in Silicon. C. J. Gallagher, *General Electric Research Laboratory.*—Single crystals of p-type silicon quenched from high temperatures, show marked changes in room temperature resistivity. Quenched samples are less p-type, suggesting that quenching introduces donor states in the forbidden band. Measurements of resistivity *vs* temperature give activation energies ranging from 0.35 to 0.40 ev above the valence band. Donor density (N_D), as deduced from the activation energy, acceptor density, and position of the Fermi level, varies with quench temperature according to the relation $N_D=N_0\exp-E/kT$, where $N_0\cong10^{22}$ cm^{-3} and $E=1.7$ ev. Quench temperatures ranged from 800°C to 1350°C The density of donors observed at 1350°C was about 10^{17} cm^{-3}. Quenching was done by heating in an all quartz furnace in argon, and dropping the crystal into a silicone oil bath. Small cross-section samples were used to minimize inhomogeneities. Rapid quenching is essential since annealing effects are observed at temperatures above 100°C. At 200°C, samples anneal back to their initial resistivities in two hours, with a time constant for the initial disappearance of donors of about 10 minutes.

T8. Properties of Zn-Doped Germanium. H. H. Woodbury and W. W. Tyler, *General Electric Research Laboratory.*—In addition to the 0.03 ev level observed by Dunlap,[1] Zn introduces a deeper acceptor level 0.09 ev from the valence band of Ge. The presence of two acceptor levels in equal concentrations is indicated by the temperature dependence of Hall coefficient in Zn-doped crystals containing no other impurities. The energy of the 0.09 ev level is most accurately obtained from the temperature dependence of Hall coefficient for samples in which the lower Zn levels have been compensated. No evidence for more than two Zn levels has been obtained in samples for which both the 0.03 ev and 0.09 ev levels have been compensated. Thus Zn is a double-acceptor impurity similar to other elements (Fe, Co, Ni, Mn) with a $4s^2$ configuration. The maximum Zn concentration obtained in single crystals of Ge is about 2×10^{18} cm^{-3}. Appreciable evaporation of Zn from the Ge melt during crystal growth precludes accurate determination of the distribution coefficient. However, Hall measurements on samples which crystallized immediately after Zn doping of the melt give k_0 values of $4\pm2\times10^{-4}$ for a variety of growth rates and Zn concentrations.

[1] W. C. Dunlap, Jr., Phys. Rev. **96**, 40 (1954).

T9. Scattering of Carriers from Doubly Charged Impurity Sites in Germanium. W. W. Tyler and H. H. Woodbury, *General Electric Research Laboratory.*—The effect of charged impurity sites on carrier mobility in Ge has been studied in both equilibrium and photoconductivity measurements. At 300°K the relative magnitude of hole mobility in Zn-doped and Ga-doped crystals indicates that the scattering cross section for doubly charged Zn sites is four times that for Ga sites. On cooling, Zn-doped crystals show regions of increasing mobility corresponding to the conversion of doubly to singly charged sites (0.09 ev freeze-out) and from singly charged to neutral sites (0.03 ev freeze-out). For compensated n-type samples containing double-acceptor impurity sites, intrinsic photoconductivity experiments indicate that an increase in free electron concentration is accompanied by an increase in electron mobility due to unit reduction of charge associated with hole trapping at the impurity sites. Changes in mobility are consistent with the Z^2 scattering law. In heavily doped Ge crystals (Mn,Zn), this mobility increase represents an appre-

ciable fraction of the photoconcudtivity. On saturation of hole trapping (Fe- and Mn-doped samples) the steady-state concentration of trapped holes is approximately equal to the impurity concentration. Thus hole trapping is unambiguously identified with specific double-acceptor impurities.

T10. Valence Bond Calculations of Acceptor Energies in Silicon and Germanium. R. G. SHULMAN, *Bell Telephone Laboratories.*—Recent experiments[1] have shown that boron, aluminum, gallium, and indium, acting as acceptors in silicon, have levels located at different energies in the forbidden gap. Optical measurements[2] indicate that the variation is primarily in ground state energies while energies of the excited nonpenetrating p-type states are relatively constant. These differences indicate the necessity of considering the specific contribution of the acceptor atom. Energies of tight bonding models are calculated using Morse curves to approximate interatomic potentials. The additional binding energy increases sharply from gallium to indium in qualitative accord with experiment. Silicon levels are more sensitive to the acceptor atom than germanium.[3] This can be understood by treating the additional binding energy as a perturbation in an effective mass calculation.

[1] Morin, Maita, Shulman, and Hannay, Phys. Rev. **96**, 833 (1954).
[2] Burstein, Picus, Henvis, and Lax, Phys. Rev. **98**, 1536 (1955).
[3] T. H. Geballe and F. J. Morin, Phys. Rev. **95**, 1085 (1954).

T11. Precipitation of Cu in Plastically Deformed Germanium. A. G. TWEET, *General Electric Research Laboratory.*—Bars of p-type Ge (5–15 ohm-cm)$\sim$1 mm$\times$2.5 mm$\times$20 mm have been twisted 30° and straightened in 90% N_2 and 10% H_2 at 500°C–525°C. These samples, together with similar undeformed specimens, were then saturated with Cu[1] at 700°C in H_2. Upon annealing at 450°C in H_2 it was observed that the Cu acceptor concentration, as determined by Hall effect measurements, is given by $N(t)=N_0e^{-t/\tau}$ for all specimens during most of the annealing process. N_0 is the initial acceptor concentration due to Cu and t is the time. For the deformed samples $\tau\cong 1$ hour, while for the undeformed samples τ is markedly greater, $\tau>60$ hours. These data are consistent with some observations by Logan[2] upon the same system. If the precipitation is diffusion limited, which is consistent with the above rate law, and if the dislocations are copper sinks, these data indicate that the effective copper diffusion coefficient at 450°C is very much smaller than that obtained by extrapolating Fuller's data.[1] Such a reduction in diffusion coefficient would result if the Cu^+ concentration is very small.

[1] Fuller, Struthers, Ditzenberger, and Wolstirn, Phys. Rev. **93**, 1182 (1954).
[2] R. A. Logan, Phys. Rev. **99**, No. 6 (1955).

T12. Polarization of Impurities in Germanium.* F. D'ALTROY AND H. Y. FAN, *Purdue University.*—Attenuation and phase shift of 3 cm microwaves in transmission through germanium were measured at 4.2°K, at which temperature the dc resistivity of the samples used was orders of magnitude higher than at room temperature. In pure samples, the dielectric constant, ϵ, obtained is 16 ± 0.5. In samples, with a carrier concentration of the order of 10^{17} cm^{-3} in the exhaustion range, higher ϵ and conductivities higher than σ_{de} were observed. The effect is attributed to the polarization and absorption associated with neutral impurities. This effect is superimposed on the carrier effect which is the only one responsible for the dc conductivity. The polarizability per neutral impurity atom increases with the concentration of the dominant impurity. Impurity ionization energy was estimated using the hydrogenic model. Data for samples with very low σ_{de} and negligible carrier effect give $E_i=0.0094$ ev for antimony and $E_i=0.0076$ ev for gallium at an impurity concentration around 10^{16} cm^{-3}. At concentrations close to 10^{17} cm^{-3}, estimated E_i drops to about 0.0045 ev. From the carrier effect, it was estimated that the conductivity effective mass is over 1000 m. This is in agreement with the hypothesis that the dc conductivity is associated with carriers in an impurity band of high effective mass.

* Work supported by a Signal Corps Contract.

T13. Surface States on Silicon. H. STATZ, G. A. DEMARS, L. DAVIS, JR., AND A. ADAMS, JR., *Raytheon Manufacturing Company.*—Measurements of the conductivity of p-type inversion layers on n-type silicon have been made. The measurements correspond to experiments carried out with germanium.[1] Steady state conductance of the inversion layers as a function of bias voltage can again be interpreted by assuming such a large total density of surface states that the quasi-Fermi level at the surface cannot shift by a measurable amount with respect to the energy bands. After the bias voltage is changed, the conductance again approaches very slowly a new equilibrium value. The time constant of this transient may be of the order of one hour and thus is longer than the corresponding ones observed for germanium. The transient behavior can be explained in terms of "slow" surface states on the silicon oxide surface and "fast" states at the silicon-silicon oxide interface. Analysis of nonsteady state conductance curves gives a single energy level for the fast states with an energy of approximately 0.4 ev. below the middle of the energy gap. For the investigated specimen, the density of these states is approximately 10^{12} states/cm^2 and therefore higher than the corresponding densities found on germanium surfaces.

[1] deMars, Statz, and Davis, Phys. Rev. **98**, 539 (1955), and Statz, Davis, and deMars, Phys. Rev. **98**, 540 (1955).

SATURDAY AFTERNOON AT 1:45

Kent 106

(V. A. JOHNSON presiding)

Semiconductors, III

U1. Neutron Irradiated Silicon.* THOMAS A. LONGO AND DAVID KLEITMAN, *Purdue University.*—After fast neutron irradiation at 45°C[1] the temperature dependence of Hall coefficient and resistivity of both n-type and p-type single crystal silicon samples indicated that intrinsic behavior was approached in each sample. A 1.75μ peak in the optical absorption coefficient was observed. This peak, previously observed in polycrystalline silicon,[2] is believed to result from optical excitation rather than ionization of an introduced defect level since it is not accompanied by an increase in photoconductivity. Appreciable photoconductivity was observed beyond the fundamental region to about 1.5μ after which there is a sharp drop with a shoulder in the region between 2 and 3μ. Annealing experiments were continued on a polycrystalline

p-type silicon sample which had been previously irradiated with fast neutrons.[3] After annealing at temperatures ranging 150°C to 250°C the slopes of the Hall coefficient and resistivity *vs* $10^3/T$ decreased suggesting the rearrangement of introduced defect levels accompanying annealing. During annealing the absorption peak at 1.75μ gradually disappears and absorption extending past 30μ increases.

* Supported by a Signal Corps contract.
[1] Samples irradiated by the Oak Ridge Solid State Group.
[2] Becker, Fan, and Lark-Horovitz, Phys. Rev. **85**, 730(A) (1952).
[3] R. W. Dreyfus, M.S. thesis, Purdue University, 1953.

U2. Deuteron Irradiation of Germanium at 90°K.* D. KLEITMAN AND T. A. LONGO, *Purdue University.*—Layers of germanium single crystals 100μ thick have been irradiated at 90°K with 9.6-Mev deuterons from the Purdue cyclotron. The initial rate of carrier removel with flux, $dn/d\varphi|_0$ depends upon the Fermi level (or initial carrier concentration). Rate of carrier removal decreases with irradiation. For two n-type samples with $n_0 = 9.9\times10^{13}$ cm^{-3} and 2.2×10^{15} cm^{-3} respectively, $dn/d\varphi|_0$ was -0.7×10^3 cm^{-1} and -3.5×10^3 cm^{-1}; the samples were converted to p-type after fluxes of 7×10^{11} deut./cm^2 and 3.5×10^{13} deut./cm^2 respectively. After warming to 300°K converted samples remained p-type. Incremental conductivity, $\Delta\sigma$, under white light illumination, increases with bombardment of n-type material, (minority carrier trapping), then falls, passing through a minimum just after conversion to p-type. After conversion, $\Delta\sigma$ again rises then finally falls off after prolonged bombardment. A shoulder to the fundamental photoconductivity near 2.3μ, and a peak at 3.5μ appear in n-type samples before conversion. After conversion a negative $\Delta\sigma$ was observed near 2.1μ, due to electron excitation from a discrete level to the conduction band and subsequent carrier recombination. The photoconductive observations are similar to those after electron bombardment.[1]

* Supported by a Signal Corps contract.
[1] Stoeckmann, Klontz, Fan, and Lark-Horovitz, Phys. Rev. **98**, 1535 (1955).

U3. Thresholds for Electron Bombardment Induced Lattice Displacements in Si and Ge. PAUL RAPPAPORT AND JOSEPH J. LOFERSKI, *RCA Laboratories.*—In a recent letter[1] we presented preliminary results of experiments designed to locate the threshold energy for production of defects, probably vacancy-interstitial pairs, in Si and Ge, by high-energy electron bombardment. The method consisted of observing the properties of p-n junctions during bombardment as a function of the energy of the electrons (V_B). Because of limitations in the Van de Graaf machine, only upper limits to the thresholds were reported. However, recent improvements in the machine have made definitive experiments possible using the same technique. The significant results are that no radiation damage (at 300°K) was observed for electrons with $V_B < 145$ kev in Si and $V_B < 325$ kev in Ge. The maximum energy which can be imparted to an atom by an electron of threshold energy (which is interpreted as the minimum energy expended in generating a vacancy-interstitial pair, $E_{L\min}$) is found to be 12.9 ev for both Si and Ge. Our results should be compared to (a) $E_{L\min} = 31$ ev deduced by Klontz from bombardment induced resistivity changes at 90°K, (b) the Wigner energy, $E_{L\min} \approx 25$ ev, (c) and the speculation by Kohn,[2] that $E_{L\min} < 15$ ev in Ge.

[1] J. J. Loferski and P. Rappaport, Phys. Rev. **98**, 1861 (1955).
[2] W. Kohn, Phys. Rev. **94**, 1409(A) (1954).

U4. Tracer Studies on Radiation Damaged Graphite.* G. L. MONTET, A. F. KURS, AND G. R. HENNIG, *Argonne National Laboratory.*—A study of the distribution of displaced carbon atoms in radiation damaged graphite[1] has been made using a radioactive tracer technique. Radioactive carbon (C^{11}) atoms produced by neutron or γ-ray bombardment occupy interstitial positions and act as tracers for displaced atoms. After partial annealing the distribution of the radioactive atoms was determined by controlled oxidation of the graphite and counting of carbon dioxide gas samples. The experiments indicate that appreciable motion of the displaced atoms begins at 400°C and ceases at 800°C, although complete reintegration with the lattice is achieved only by heating to 1700°C. The behavior during annealing of the displaced atoms was found to be very sensitive to the amount of damage produced in graphite. Analysis of the data on the assumption that graphite consists of perfect regions surrounded by mosaic boundaries leads to an average linear extent of the "perfect regions" of about 2600 A. A bombardment of 10^{17} neutrons-cm^{-2} introduces enough traps within the "perfect region" so that only one-fifth of the displaced atoms can reach the boundaries.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Burton, J. Phys. Colloid Chem. **51**, 618 (1947).

U5. Excess Noise in Plastically Deformed Germanium. JAMES J. BROPHY, *Armour Research Foundation.*—The excess noise levels of several samples of plastically deformed germanium have been examined. Single crystal, n-type germanium specimens of five ohm-centimeter resistivity were plastically deformed by bending in air at 600°C. After deformation, the samples were still n-type but the resistivity was increased by a factor of about two. These were sandblasted into 'bridges" similar to those used by Montgomery[1] to eliminate effects due to noisy electrodes. The excess noise level is increased three or four orders of magnitude by deformation and may be represented by $\langle \Delta v^2 \rangle = KI^{1.6} f^{-1.0}$ volts^2/cycle, where $\langle \Delta v^2 \rangle$ is the mean square excess noise voltage, I is the sample current in milliamperes, f is the frequency, and K is a constant of the order of 10^{-15}. The usual inverse frequency spectrum characteristic of excess noise is observed, but the current dependence differs from the usual square law variation expected for a conductivity modulation phenomena.

[1] H. C. Montgomery, Bell System Tech. J. **31**, 950 (1952).

U6. Electrical Properties of Mg_2Sn at Low Temperatures. W. R. HOSLER AND H. P. R. FREDERIKSE, *National Bureau of Standards.*—Conductivity and Hall coefficient of several n- and p-type single crystals were measured in the range from 2 to 300°K. In most specimens both acceptors and donors are present. The number of carriers at exhaustion lies between 10^{15} and 10^{17} cm^{-3}. Maxima in the Hall coefficient were observed in all samples at low temperatures, while the slope of the conductivity becomes very small in this region. The position of the Hall maxima varies between 6 and 66°K; impurity activation energies (as calculated from the slope of $RT^{\frac{1}{2}}$ *vs* $1/T$) range from 0.003 to 0.03 ev. Similar effects have been observed in Ge and InSb; this behavior has been attributed to impurity band conduction.[1] The Mg_2Sn compound shows an additional feature: all samples approach about the same Hall coefficient (4500–6500 cm^3/coulomb) in the helium range independent of the value at exhaustion. The product $R\sigma$ of different samples lies between 15 and 30 cm^3/volt-sec at very low temperatures.

[1] Hung and Gliessmann (1950); Hrostowski (1955); Fritzsche, Phys. Rev. **99**, 400, 406 (1955).

U7. Electrical Properties of the Semiconductors Mg_2Si and Mg_2Ge.* C. R. WHITSETT AND G. C. DANIELSON, *Iowa State College.*—The electrical resistivities and Hall coefficients of single crystals of Mg_2Si and Mg_2Ge have been measured in the temperature range 60°K to 1000°K. Since the Hall coefficients were always negative, electron conduction always predominated over hole conduction in these particular samples. At 300°K the densities of electrons from impurity levels were 10^{17} to 10^{18} per cm^3 and the Hall mobilities were about 200

cm²/volt-sec. Above 300°K the temperature dependence of the mobility in Mg_2Si was given by $9(10^8)T^{-1}$ cm²/volt-sec, but in Mg_2Ge the temperature dependence was more complicated. In the intrinsic conduction region ($T>500$°K) the resistivities were found to be given by $\rho=A\exp(\Delta E/2kT)$ with $A=0.00032$ ohm-cm and $\Delta E=0.48$ ev for Mg_2Si and $A=0.00012$ ohm-cm and $\Delta E=0.64$ ev for Mg_2Ge. It was estimated that for Mg_2Si $\mu_n/\mu_p\sim1.3$ [illegible] for Mg_2Ge $\mu_n/\mu_p>2.5$. The effective masses of electron [illegible]d holes in Mg_2Si were estimated to be respectively 1.8 [illegible]d 2.0 times the free electron mass.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

U8. Reduction of Charge Carrier Concentration in InSb at 4.2°K by a Strong Magnetic Field. R. W. KEYES AND R. J. SLADEK, *Westinghouse Research Laboratories.*—Hall measurements on *n*-type InSb indicate that the concentration of mobile charge carriers is not drastically reduced by cooling from 77°K to 4.2°K. Adams[1] has pointed out that at magnetic fields of about 10 000 gauss the cyclotron radius becomes equal to the Bohr radius in *n*-type InSb and consequently an appreciable lowering of the impurity energy level is to be expected at higher fields. To check these ideas the electrical resistivity and Hall effect of two *n*-type InSb samples[2] having donor concentrations of $\sim10^{14}$ and $\sim10^{16}$ cc^{-1} were measured at 4.2°K in a (transverse) magnetic field of intensities up to 82 500 gauss using the high magnetic field facilities of the Cryogenics Branch at the Naval Research Laboratory. The Hall measurements indicate that a large reduction of the charge carrier concentration occurred in the $\sim10^{14}$ sample but not in the $\sim10^{16}$ sample. In addition the Hall mobility was strongly field dependent in both samples. The temperature dependence of the Hall coefficient showed no anomalies of the type usually attributed to impurity band formation.

[1] E. N. Adams (private communication).
[2] Obtained from Dr. S. Kurnick, Chicago Midway Laboratories.

U9. Electrical Breakdown in InSb at Low Temperature. RALPH BRAY, *Purdue University.*—Reversible electrical breakdown in *p*-type InSb has been observed at 4.2°K under pulse conditions. It is characterized by a vertical rise in current, followed by a negative resistance region, and results in increase in conductivity by a factor $\gtrsim10^4$. The effect resembles low temperature breakdown in Ge,[1] which has been attributed[2] to free carrier multiplication by impact ionization of neutral impurities. Breakdown occurred at 43 volt/cm in samples having $\sim4\times10^{15}$ holes/cm³ at exhaustion, and Hall mobility ~4000 cm²/volt sec at 77°K. At low voltage, at 4.2°K, the samples exhibited the Hung anomaly[3] in Hall effect and resistivity, and gave, in transverse magnetic field (3000 gauss), the anomalous *negative* magnetoresistive ratio,[3] $[(\Delta\rho/\rho_H)\sim-2\%]$. At higher voltage, in the prebreakdown region of slowly rising conductivity, a *reversal to positive* magnetoresistive ratio was obtained. The magnetic field increased the critical breakdown electric field. It seems therefore that the negative magnetoresistive effect is associated solely with the conduction in the impurity band.

[1] F. J. Darnell and S. A. Friedberg, Phys. Rev. **98**, 1860 (1955). This latest reference contains the previous references.
[2] Sclar, Burstein, Turner, and Davisson, Phys. Rev. **91**, 215(A) (1953).
[3] H. Fritzsche and K. Lark-Horovitz, Phys. Rev. **99**, 400 (1955).

U10. Plasma Resonance in Semiconductor Crystals. G. DRESSELHAUS, A. F. KIP, AND C. KITTEL, *University of California, Berkeley.*—Observations are reported of an electron plasma resonance absorption line in a magnetic field in an *n*-type crystal of InSb at 9000 and 24 000 Mc and at 4° and 77°K. The magnitude of the plasma frequency and its dependence on rf frequency and on the orientation of the figure axis of the specimen relative to the static magnetic field are in approximate agreement with the elementary theory of the plasma resonance developed previously by the authors. For a spherical sample and an isotropic effective mass m^*, the resonance occurs at a magnetic field such that $\lambda_c=\omega-\omega_p^2\omega^{-1}$, where $\omega_c=eH/m^*c$, ω is the applied microwave angular velocity,

$$\omega_p^2=\frac{4\pi Ne^2}{3m^*}\left(1+\frac{4\pi}{3}\chi\right)^{-1},$$

N is the carrier concentration, and χ is the dielectric susceptibility. The line shape for experiments carried out under conditions of carrier modulation are "derivative like" due to the dependence of the resonance frequency on carrier concentration. The effect can be used to determine experimentally the value of the charge density. The experimental measurements of carrier density in InSb thus far have been only approximate because of the difficulty of obtaining good geometry at the small dimensions required to stay within the skin depth limitation.

U11. Preparation and Electrical Properties of Bi_2Te_3.* T. C. HARMAN, S. E. MILLER, AND H. L. GOERING, *Battelle Memorial Institute.*—Bi_2Te_3 has been prepared by a number of techniques from zone-melted Bi, and Te which has been purified by multiple distillation. For thermoelectric device applications, it was found that the best technique for preparing both *n*-type and *p*-type Bi_2Te_3 is quenching the compound from above its melting point and annealing for long periods of time near its melting point. For the preparation of single crystals for fundamental studies, the best technique was found to be zone melting in a tellurium atmosphere. Bi_2Te_3 dissociates to some extent at the melting point and the elements, Bi and Te, have segregation coefficients near unity. Iodine and excess Te are *n*-type impurities in Bi_2Te_3, while Pb and excess Bi are *p*-type. The resistivity and thermoelectric power have been measured as functions of temperature from 200°K to 700°K for *n*-type and *p*-type specimens with varying impurity concentrations. A *p*-type specimen had a thermoelectric crossover at 450°K. An *n*-type specimen had a thermoelectric power of -180 μv/°C at 300°K. The intrinsic resistivity slope indicates a small energy gap.

* This work is supported by a contract with the Tellurium Development Committee.

SATURDAY AFTERNOON AT 1:30

Mandel Hall

(L. W. ALVAREZ presiding)

Invited Paper

V1. Properties of Heavy Mesons Produced at the Bevatron. GERSON GOLDHABER, *University of California, Berkeley.* (30 min.)

Heavy Mesons and Hyperons

V2. Production of Hyperons and *K*-Mesons in the High Energy* π^- Beam of the Berkeley Bevatron. MARCEL SCHEIN AND D. M. HASKIN, *University of Chicago.*—Stacks of Ilford G-5 pellicles have been exposed to the 4.8 Bev and 3.0 Bev negative pion beams of the Berkeley Bevatron. A number of heavy unstable particles have been found and have been traced back to the star in which they originate. Of particular interest are cases of K^- production, since it can be assumed that they originate according to the reaction

$$\pi^- + P \rightarrow K^+ + K^- + N.$$

The observed K^+/K^--ratio is roughly one in the π^- beam in contrast to 100 in the proton beam, which supports this hypothesis. In addition, one event has been located in which a π meson undergoes a nuclear collision resulting in a track of minimum ionization and a K^+-meson. No other fragments are visible in the collision. This fact together with the approximate validity of conservation laws in the elementary interaction supports the above suggested interpretation.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V3. Hyperfragments in Light Elements Produced by the Berkeley Bevatron.* DANIEL LEENOV, D. M. HASKIN, AND MARCEL SCHEIN, *University of Chicago.*—A number of hyperfragments have been observed in exposures to the 3.0-Bev and 4.8-Bev π^- and the slow K^- beams of the Berkeley Bevatron, including cases of H_Λ^3* and H_Λ^4*, in which one neutron is replaced by a Λ^0 hyperon. A H_Λ^4 was produced by the nuclear capture of a Σ^- hyperon which was in turn produced by the interaction of a 3.0 Bev negative pion. It is proposed that the production of the Λ^0 results from the reaction $\Sigma^- + P \rightarrow \Lambda^0 + N$. In the case in question, a 255 μ long track with charge one stops and undergoes a colinear decay into a negative pion and a He^4 recoil. The pion was followed to the end of its range and the total energy release in the decay was found to be 50.8 Mev, giving a binding energy for the Λ^0 in H_Λ^4* of 7 ± 2 Mev. Cases of tritium hyperfragments giving events with two protons and a π meson will be discussed. The binding energy of the Λ^0 hyperon in tritium was found to be 5 ± 2 Mev.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V4. Analysis of Capture Stars of K^--Mesons from the Berkeley Bevatron.* D. M. HASKIN, D. B. WILLIAMS, E. GOODMAN, AND MARCEL SCHEIN, *University of Chicago.*—K^--stars produced by 6.2 Bev protons have been found in a magnetically analyzed channel of the Berkeley Bevatron. All of the observed events are consistent with the scheme of Gell-Mann and Pais. The following reactions are possible: $K^- + (P,N,P,N) \rightarrow (\Lambda^0,\Sigma^+,\Sigma^0,\Sigma^-) + \pi^0$; $K^- + (P,N,P) \rightarrow (\Sigma^+,\Lambda^0,\Sigma^0) + \pi^-$; and $K^- + P \rightarrow \Sigma^- + \pi^+$. The average prong number for the K^--stars is 3.3 indicating that Λ^0 hyperons must frequently escape from the absorbing nucleus. Two K^--stars have been found with the unusually large number of 10 visible prongs. The energies of the emitted π mesons fall into at least two distinct groups: (a) 50–80 Mev; (b) 100–140 Mev. This is in good agreement with the abovementioned reactions. Pions in group (b) are much less frequent than those in (a), indicating a higher recapture probability of the π^- at higher energy. Several cases of positive and negative hyperons and hyperfragments have been found and a few individual cases will be discussed. In one case, the capture of the K^- leads to the emission of two π mesons, one of them carrying an energy of 140 Mev and the other one much lower. The event can possibly be interpreted as: $K^- + N \rightarrow \Lambda^0 + \pi^-$ assuming the Λ^0 decays from an orbit inside the nucleus.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V5. Nuclear Collisions of 5.7 Bev Protons and 3.0 Bev π^- Mesons.* R. E. CAVANAUGH, D. M. HASKIN, AND MARCEL SCHEIN, *University of Chicago.*—Stars produced by 5.7-Bev protons and 3.0-Bev π^- mesons from the Berkeley Bevatron have been found by the method of following along tracks in Ilford G-5 emulsion. The average prong number for the proton stars is 10.7 and for the pion stars 9.3. The maximum prong numbers observed are 30 and 20, respectively. The average number of visible shower tracks is 2.1 for the proton initiated stars, and 0.9 for the π^- initiated stars. The maximum number of shower tracks found amounted to 6 and 4 respectively. Among the proton events there are 3 cases where a pion is ejected into the backward hemisphere. No case of a similar kind has been found in the pion beam. From 50 events in each beam, the mean free path is found to be 37.6 ± 5.3 cm. and 35.5 ± 5.0 cm. This should be compared with the geometrical mean free path for nuclear collisions in the emulsion, which is 25 cm. The relatively large difference has interesting theoretical implications.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V6. Disintegration of Hyperfragments. J. SCHNEPS, M. S. SWAMI, AND W. F. FRY, *University of Wisconsin.**—A systematic search for hyperfragments has been made in nuclear emulsion exposed to 6 Bev protons and 3 Bev π mesons from the Bevatron; to 3 Bev protons from the Cosmotron; and to cosmic rays. A total of eighty hyperfragments have been observed. The average Z of these hyperfragments is about 5. In most cases the kinetic energy of the hyperfragments is low, i.e., less than 15 Mev. It was possible to measure the binding energy of the Λ^0 particle in 3 cases of ${}_\Lambda H^3$, ${}_\Lambda H^4$, 2 cases of ${}_\Lambda He^4$, ${}_\Lambda He^5$, ${}_\Lambda Be^7$, ${}_\Lambda Be^8$ (or ${}_\Lambda Be^9$), ${}_\Lambda Be^{10}$ (or ${}_\Lambda Be^{11}$), and ${}_\Lambda C^{11}$. In general for $Z<3$ mesonic decay of hyperfragments is predominant while for $Z>3$ the nonmesonic decay is predominant. However an example of the nonmesonic decay of helium and of the mesonic decay of carbon have been observed. An estimate of the momentum of the bound Λ^0 hyperon can be obtained for the light nuclei.

* Supported in part by the Atomic Energy Commission and by the Graduate School.

V7. Proton Nucleus Collisions at 6 Bev.* U. HABER-SCHAIM, *University of Illinois.*—An analysis of stars produced by the proton beam of the Bevatron will be presented. The frequency distributions of heavy and light tracks and the angular distribution of light tracks will be discussed in relation to the mechanism of the proton nucleus collision.

* This work is supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V8. The Spin of the τ^+ Meson.* D. M. RITSON, A. ODIAN, B. T. FELD, AND A. WATTENBERG, *M. I. T.*—Measurements of the angular correlation and energy distribution of the π^- from 54 τ^+ mesons have been studied in a large emulsion stack irradiated in the Berkeley K^+-meson beam. An analysis based on the suggestions of Dalitz shows the π^- energy distribution of these 54 events to be asymmetric and favors a τ meson with spin 1 and even parity.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V9. Effects of Angular Momentum on τ-Decay Schemes.* BERNARD T. FELD, *M. I. T.*—The angular correlation and energy distribution in the decay $\tau^\pm \rightarrow \pi^\pm + \pi^+ + \pi^-$ can be described, according to the method of Dalitz, in terms of the angular momenta l and L of the odd- and the *di-pi*, respectively

For l or $L>0$, angular momentum barrier penetration effects influence the energy distributions. Since the barrier penetration factors depend on the range of the forces between the decay particles, different assumptions as to this range lead to different results for the expected energy distribution of the odd π. Typical results will be shown to illustrate this effect. Another barrier effect is in the relative probability of the different possible decay modes, especially in cases in which there are two of comparable probability (e.g., a τ of spin 2 and negative parity can decay by $l=0$, $L=2$ and $l=2$, $L=0$). Angular distributions will be shown, under various assumptions concerning the force range, for these ambiguous decay schemes. Some of these effects have been discussed by Fabri at the Pisa Conference on Elementary Particles.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V10. π^--P Collisions at 1.0 Bev.* W. D. WALKER AND W. D. SHEPHARD, *University of Wisconsin.*—Interactions of 1.0 Bev. π^- mesons with protons have been observed using the Brookhaven hydrogen diffusion Chamber. The present tabulation includes about 160 interactions. The cross sections observed are

Reaction products	σ in mb
$\pi^-+P(\theta_\pi<40°)$	20
$\pi^-+P(\theta_\pi>40°)$	6
$\pi^++\pi^-+N$	11.5
$\pi^-+\pi^0+P$	6.5
3π's+nucleon	~3
Associated pairs	~1

The diffraction cross section seems to be nearly equal to the inelastic cross section. This would indicate that for the $I=\frac{1}{2}$ state of the π^-P system that waves of $l=0,1,2\hbar$ are almost completely absorbed. This corresponds to a range of interaction of about 8×10^{-14} cm. The inelastic processes are rather different from those observed at 1.5 Bev as far as the angular and momentum distributions. The angular distribution of the nucleons is nearly isotropic which is in contrast to the results at 1.5 Bev.

* This work has been supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

V11. Production of Heavy Unstable Particles in π^-P Collisions at 1.0 Bev.* W. D. SHEPHARD AND W. D. WALKER, *University of Wisconsin.*—In the course of the experiment on π^-P collisions at 1.0 Bev 5 examples of associated production in the gas have been found. There are three cases of $\Lambda^0-\theta^0$, one of "Σ^0"$-\theta^0$,[1,2] and one of Σ^--K^+. The total cross section for the production of associated pairs at this energy seems to be about 1 mb. The hyperons, as observed by the Brookhaven group,[2] seem to decay preferentially in the plane of production. The angles observed between the plane of production and plane of decay of the hyperon are $20°\pm5°$, $40°\pm10°$, $36°\pm8°$, $10°\pm5°$, $10°\pm5°$. The observed angles of production of the hyperons in the π^-P center of mass seem consistent with an isotropic distribution. This result seems to hold for the Λ^0's emerging from the walls of the chamber also. These results are to be compared with the Brookhaven group's results at 1.4 Bev in which the hyperons seem to go preferentially in the backward hemisphere.[1]

* This work has been supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **98**, 121 (1955).
[2] W. D. Walker, Phys. Rev. **98**, 1407 (1955).

V12. Double-Plate Cloud-Chamber Study of V^0-Particles. I. Classification. I. C. GUPTA, W. Y. CHANG, AND A. SNYDER, *Purdue University.*—During the past year, our two rectangular cloud chambers[1] have been used separately for the study of V^0-particles, each containing one 2-inch Pb plate and two thinner ones ($\frac{1}{8}$ and $\frac{1}{4}$ inch). Up to now 138 V-events have been obtained from about 60% of the films taken. 66 events show clear association with the nuclear interactions in the first or second plate and have been analyzed according to the $\alpha-\epsilon$ projection procedure.[2] $\alpha-\epsilon$ plots were prepared beforehand respectively for the θ^0 and Λ^0 particles of different momenta. For each event, α and ϵ values were found from the measured angles of the two decay products relative to the V^0-particle. With the help of the $\alpha-\epsilon$ plots, two alternative sets of ionizations of the decay products were obtained and compared with their measured ionizations. In this way, 31 events have been classified as θ^0 particles, 30 as Λ^0 particles, and 5 as neither. Coplanarity and isotropy of emission in the rest system are being investigated respectively from the distribution of the angle between the plane of the V-event and direction of the V^0-particle and that of the $\alpha-\epsilon$ points in the $\alpha-\epsilon$ plots.

[1] G. del Castillo, Ph.D. Thesis, Purdue University, 1954; Phys. Rev. **98**, 1163 (1955).
[2] J. Podolanski and R. Armenteros, Phil. Mag. **45**, 13 (1954); D. B. Gatyher, Phil. Mag. **45**, 570 (1954).

V13. Double-Plate Cloud-Chamber Study of V^0-Particles. II. Mean Decay Times of θ^0 and Λ^0 Particles. A. SNYDER, W. Y. CHANG, AND I. C. GUPTA, *Purdue University.*—The mean decay times of the 31 θ^0 particles and 30 Λ^0 particles (see other abstract) have been calculated according to the statistical procedure of Bartlett.[1] For each event, the decay length, the "total potential" decay length, and the "plate-potential" decay lengths were measured from the same point 0.2 cm below the plate surface concerned. The terminal point of the "total potential" decay length was taken as one at which the shortest prong would have 3 cm from the illumination edge or the last plate. Since the V-events in the last gas space were ignored, the terminal point was not extended to this gas space. The velocity of the V^0-particle was calculated from the two distances of its $\alpha-\epsilon$ point to the foci of the $\alpha-\epsilon$ plot. Hence, the different decay lengths were converted into decay times. According to the statistical procedure for T/τ being small, the mean decay time for the 31 θ^0 particles is found to be $\left(1.83^{+0.35}_{-0.25}\right)\times10^{-10}$ sec, and for the 30 Λ^0 particle $\left(3.47^{+0.70}_{-0.49}\right)\times10^{-10}$ sec. Methods of measurements have been examined and will be discussed.

[1] M. S. Bartlett, Phil. Mag. **44**, 249, 1407 (1953).

V14. K-Meson Lifetimes.* LUIS W. ALVAREZ, FRANK S. CRAWFORD, JR., MYRON L. GOOD, AND M. LYNN STEVENSON, *University of California, Berkeley.*—Since the various species of K-mesons produced at the Bevatron have masses equal within the rather small experimental error,[1] it becomes a critical matter to see if the lifetimes of the separate species are the same, or different. A counter experiment to investigate this point is being carried out. K^+-mesons, momentum-analyzed in the magnet arrangement of Kerth and Stork, are detected by a scintillation counter telescope and brought to rest in one of the scintillators. A side counter telescope of four counters detects the decay fragments, distinguishing between $K_{\pi2}$, $K_{\mu2}$, and τ decays. In one experiment in which 127 $K_{\mu2}$'s and 72 $K_{\pi2}$'s were observed to decay, preliminary results give equal lifetimes for the $K_{\mu2}$ and $K_{\pi2}$, approximately 1.3×10^{-8} sec. Results for the τ are not yet clear-cut.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. W. Birge *et al.*, Phys. Rev. **99**, 329 (1955).

SATURDAY AFTERNOON AT 1:30

Eckhart 133

(M. B. SAMPSON presiding)

Reactions of Transmutation, II; Coulomb Excitation, Fission

W1. (p,α) Reactions in Cl and K. E. ALMQVIST, R. L. CLARKE, AND E. B. PAUL, *Chalk River Laboratories.*—The reactions $Cl^{35}(p,\alpha)S^{32}$, $Cl^{37}(p,\alpha)S^{34}$, $K^{39}(p,\alpha)A^{36}$, and $K^{41}(p,\alpha)A^{38}$ have been observed using a magnetic spectrometer, and their excitation functions and Q-values measured. Targets that measured about 1 kev thick for 1.9-Mev protons were used. The energy scale of the Van de Graaff generator was established by observing the $Li^7(p,n)Be^7$ threshold. The magnetic analyzer was calibrated using groups of α particles from reactions of precisely known Q-values. All measurements were made at 90° to the beam. The Q-values are

$Cl^{35}(p,\alpha)S^{32}$	$Q=1.865\pm0.015$ Mev
$Cl^{37}(p,\alpha)S^{34}$	$Q=3.015\pm0.015$ Mev
$K^{39}(p,\alpha)A^{36}$	$Q=1.267\pm0.020$ Mev
$K^{41}(p,\alpha)A^{38}$	$Q=4.002\pm0.015$ Mev.

Eighteen well-defined resonances corresponding to levels in A^{36} were observed in the $Cl^{35}(p,\alpha)$ reaction between 1.30- and 2.51-Mev proton energy. Twenty-two resonances corresponding to levels in A^{38} were observed in the $Cl^{37}(p,\alpha)$ reaction between 1.0- and 2.5-Mev proton energy. There is published data[1] up to 1.8 Mev which agrees with the present results.

[1] Brostrom, Madsen, and Madsen, Phys. Rev. **83**, 1265 (1951).

W2. Excitation Functions for Alpha-Induced Reactions on Lead.* WALTER JOHN,† *University of California.*—The excitation functions for alpha-induced reactions on several lead isotopes have been measured. A procedure has been developed for preparing enriched lead isotope targets by evaporation. Stacked foils were bombarded by the alpha-beam of the 60-inch cyclotron. The induced polonium alpha activities were separated by alpha pulse-height analysis. The measured excitation functions for $Pb^{206}+\alpha$ were compared to the excitation functions for $Bi+p$. Since the compound nucleus formed is the same, the comparison gives a test of the predictions of Bohr's compound nucleus theory. The ratios of corresponding cross sections are in agreement with the compound nucleus theory. However, the excitation functions are displaced in energy by an amount not predicted by the theory. The discrepancy, 0.8 Mev is slightly outside of the errors. The comparison of $Ni^{60}+\alpha$ and $Cu^{63}+p$ made by Ghoshal[1] has been checked with more recent mass values and a discrepancy of 3.2 Mev is found. These discrepancies will be discussed.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Department of Physics, University of Illinois.
[1] S. N. Ghoshal, Phys. Rev. **80**, 939 (1950).

W3. The Photodisintegration of Lithium and Helium near 200 Mev.* J. H. SMITH AND M. Q. BARTON, *University of Illinois.*—We have made additional measurements of correlated protons and neutrons ejected from lithium and helium by 285-Mev bremsstrahlung using previously reported techniques.[1] Protons of several energies from 55 Mev to 130 Mev were observed at 75° to the x-ray beam, and the angular distributions of their correlated neutrons were measured. In general the results are consistent with a deutron-like interaction between nucleons in the complex nucleus modified by a reasonable ground-state momentum wave function. However, deviations from this model will be discussed.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] M. Q. Barton and J. H. Smith, Phys. Rev. **95**, 573 (1954).

W4. High-Energy Photoproton Emission at 175°.* C. A. TATRO AND T. R. PALFREY, JR., *Purdue University.*—The Z dependence of the cross section for emission of 50- to 75-Mev photoprotons at 175° in the laboratory has been measured. Targets of Be, C, Al, Cu, Cd, and Pb were bombarded by a 280-Mev gamma-ray bremsstrahlung spectrum from the Purdue electron synchrotron. A three-counter telescope placed behind a deflection magnet detected the emitted protons, which were identified by pulse-height analysis of photographs of the three counter pulses. Absolute cross sections have been obtained for two energy intervals, and Z dependences for three energy groups. Contrary to the results of previous experiments at more forward angles, where the cross section was found to be proportional to Z, the ratio σ/Z at 175° increases by a factor of about 1.7 between Be and Pb, rising most rapidly between Be and Al.

* Supported in part by the U. S. Atomic Energy Commission.

W5. Coulomb Excitation of Energy Levels in Br and Re. E. A. WOLICKI, L. W. FAGG, AND E. H. GEER, *Naval Research Laboratory.*—Isotopically enriched targets of KBr and metallic Re have been bombarded with protons and alpha particles. The following gamma rays have been observed as a result of Coulomb excitation: Br^{79} 219 kev; Br^{81} 278 kev; Re^{185} 126, 160, 286 kev; and Re^{187} 135, 168, 303 kev. Coincidences have been observed between the 126 and 160 and between the 135 and 168 kev gamma rays. Reduced transition probabilities have been measured. In the case of the Re isotopes, cascade to crossover ratios have been obtained. Measurements on the Re nuclei are in agreement with the results of other workers.[1,2]

[1] McClelland, Mark, and Goodman, Phys. Rev. **97**, 1191 (1955).
[2] H. Mark and G. Paulissen, Phys. Rev. **99**, 1654(A) (1955).

W6. Coulomb Excitation of In^{115m} by Alpha Particles.* R. R. MCLEOD, *Purdue University.*—The thick-target activation curve for production of the isomer In^{115m} (4.5 hours) by alpha particles in the energy range from 7 to 20 Mev has been measured. The cyclotron was utilized as the source of alpha particles. The absolute isomeric yield was determined at each alpha-particle energy from measurements of the intensity of the 335-kev gamma radiation of In^{115m}, using a well-type scintillation counter and a twenty-channel analyzer. The energy dependence of the cross section obtained from the thick-target yield is consistent with the excitation of one quadrupole level of approximately 1.5-Mev energy, from which the isomeric state is reached by spontaneous decay processes. The contribution from direct excitation of the isomeric state is negligible.

* Supported in part by the U. S. Atomic Energy Commission.

W7. Coulomb Excitation of Samarium.* B. E. SIMMONS,† K. F. FAMULARO, AND G. D. FREIER, *University of Minnesota.*—Equipment previously described[1] was used to detect gamma rays produced by proton bombardment of isotopically enriched samarium (thick oxide) targets. Results below are gamma-ray energy; isotopic origin; excitation function agreement with Coulomb excitation theory[2] for E-2 and for E-1 interactions; and, at proton energy E_p, angular distribution coefficients $a_i)_t$ in $1+0.3571a_2)_tP_2(\cos\theta)+1.143a_4)_tP_4(\cos\theta)$. The $a_i)_t$ agree with empirical E-2 results of McGowan and

Stelson[3] but not with E-2 theory.[2] Nuclear transition probabilities are being calculated.

E_γ-kev	Origin	E-2 e.f.	E-1 e.f.	$a_2)_t$	$a_4)_t$	E_γ-Mev
85±3	Sm^{154}	yes	no	0.281±0.072	−0.021±0.029	2.07
124±2	Sm^{152}	yes	no	0.346±0.033	+0.016±0.015	2.28
337±3	Sm^{150}	yes	yes	0.815±0.095	−0.069±0.039	2.61
562±8	Sm^{148}	(weak)	...	...	...	...

* This work supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Knolls Atomic Power Laboratory.
[1] Simmons, Van Patter, Famularo, and Stuart, Phys. Rev. **97**, 89 (1955).
[2] K. Alder and A. Winther, Phys. Rev. **96**, 237 (1954), and private communication, 1954.
[3] F. K. McGowan and P. H. Stelson, Phys. Rev. **99**, 127 (1955).

W8. Coulomb Excitation of Re, In, and Hg by Protons. ROBERT H. DAVIS, AJAY S. DIVATIA, R. D. MOFFAT, AND D. A. LIND, *University of Wisconsin.**—Thick targets of natural and isotopically enriched rhenium, iridium, and mercury in the form of metallic and oxide powders have been bombarded with protons of energies up to 3.2 Mev. To analyze the composite spectra, the resolution, variation of Compton shape with gamma energy, and the efficiency of the scintillation spectrometer were determined by means of absolutely calibrated gamma-ray sources. The agreement between the observed dependence of gamma-ray yield on proton energy and that predicted by Coulomb excitation theory for $E2$ transitions identified the following gamma rays (in kev) as decay radiations from Coulomb excited energy levels: Re^{185}, 125, 158, 280; Re^{187}, 135, 163, 300; Ir^{191}, 115, 133, 216, 356; Ir^{193}, 143, 230, 368; Hg^{199}, 159, 209; Hg^{200}, 375. An additional line from Hg at 424 kev was observed. The deformation parameters evaluated from the cross sections have been compared with those determined from the excitation energy; the deformation seems to fit the systematic trend already established in this mass region. The presence of the 115-kev line belonging to In^{191} implies the existence of a level at this energy in addition to the known levels at 133 and 356 kev. The error in the energy assignments depends on the complexity of the particular composite peak and varies from 1 to 3%.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

W9. Coulomb Excitation of In^{115}, I^{127}, Ta^{181}, Th^{232}, and U^{238}. AJAY S. DIVATIA, ROBERT H. DAVIS, R. D. MOFFAT, AND D. A. LIND, *University of Wisconsin.**—Gamma rays resulting from proton or alpha-particle bombardment of In^{115}, I^{127}, Ta^{181}, Th^{232}, and U^{238} were studied using a NaI(Tl) scintillation spectrometer. Gamma-ray yields were measured as a function of the incident particle energy and compared with the theory of electric excitation. Reduced transition probabilities for excitations have been obtained from absolute cross-section measurements and compared with their values based on single particle estimates. The gamma rays observed under proton bombardment are, In^{115}: 512±12 kev; I^{127}: 208±7, 392±8, 438±10, 631±10, 751±25, 941±50 kev; and Ta^{181}: 137±3, 165±4, 302±4 kev. Those observed under alpha-particle bombardment are, I^{127}: 60±2, 201±4 kev; Th^{232}: 50±5 kev; and U^{238}: 45±3 kev. The yields for the gamma rays of Ta^{181} have been compared with those obtained by Stelson and McGowan.[1] The excitation curve for the 512-kev gamma ray of In^{115} differs markedly from the theoretical $E2$ excitation curve; the gamma ray probably arises from a nuclear reaction. The excitation curves for the 392-kev and 941-kev gamma rays of I^{127} differ from the theoretical $E2$ curves to some extent; all the other gamma rays follow an $E2$ excitation function.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] P. H. Stelson and F. K. McGowan, Phys. Rev. **99**, 112 (1955).

W10. Measurement of Energy Variation of the Neutron Multiplication, η, for U^{233}, U^{235}, and Cu^{239} in the Thermal Region.* H. PALEVSKY, R. L. ZIMMERMAN, R. M. EISBERG, AND D. J. HUGHES, *Brookhaven National Laboratory.*—A new method has been developed that gives directly the variation of η, the number of neutrons produced per neutron absorbed, with energy in the thermal region in a direct and unambiguous way. A beam of thermal neutrons passes through a "thin" (1/v) counter and then falls on a thick foil of the material being investigated. The fission neutrons from the foil are detected by a scintillation counter. As essentially all the neutrons are absorbed by the thick foil the thin counter gives the absorption rate, whereas the emission rate of fission neutrons is given by the scintillation counter. In this way the ratio of the counting rates of the scintillator to the thin counter is directly proportional to η. The energy of the incident neutrons is determined by time of flight method using the Brookhaven slow chopper. The results are normalized to the known thermal value of η with no attempt at absolute calibration of the counters. Measurements have been made by this method for U^{233}, U^{235}, and Pu^{239}. The measurements made with U^{235} and U^{233} indicate that in the region from 0.01 to 0.10 ev η is constant within experimental error (±1%). In Pu^{239}, η decreases by about 15% from 0.01 to 0.1 ev.

* Work carried out under contract with U. S. Atomic Energy Commission.

W11. Energy Dependence of η for U^{235} in the Region 0.04–1.0 ev.* J. R. SMITH AND E. H. MAGLEBY, *Phillips Petroleum Company.*—Measurements have been made of the energy dependence of η, the number of fission neutrons emitted per neutron absorbed, for U^{235} in the energy region 0.04–1.0 ev. Two 5-in. Hornyak buttons on DuMont 6364 photomultiplier tubes count fission neutrons from a target of U^{235} placed between them in the Bragg beam of the MTR crystal spectrometer. A sample changer moves the target into and out of the beam, enabling a single thin BF_3 counter behind the target to serve as both flux monitor and transmission detector. The data are normalized to the Brookhaven slow chopper results, which were normalized to the thermal value of $\eta = 2.08$. Below 0.1 ev η is essentially flat. Above 0.1 ev it falls to a value of 1.9 for the 0.3-ev resonance, then rises to a peak of about 2.2 between 0.5 and 0.7 ev. In the neighborhood of 1 ev η decreases as the 1.12-ev resonance is approached.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

W12. The β^- Energy Distribution from Thermal Fission of U^{235}.* C. O. MUEHLHAUSE AND S. OLEKSA, *Brookhaven National Laboratory.*—The energy spectrum of β^- rays from thermal fission of U^{235} has been measured from 0.67 Mev to 6.7 Mev and found to be in good agreement with that predicted by E. Wigner and K. Way.[1] The spectrum and its absolute intensity was used to infer the neutrino spectrum emitted by a thermal reactor, and to compare relative rates of such reactions as $p(\nu,n)\beta^+$, $d(\nu,2n)\beta^+$, and $Cl^{37}(\nu_0,e^-)A^{37}$.

* Work performed under contract with the U. S. Atomic Energy Commission.
[1] E. Wigner and K. Way, Phys. Rev. **73**, 1318 (1948).

SATURDAY AFTERNOON AT 1:45

Cobb 110

(R. A. SAWYER presiding)

General Physics

X1. Reduction of Optical Reflectivity of Glass by Positive Ion Bombardment. R. L. HINES, *Ford Motor Company.*—Bombardment of glass by krypton positive ions with an energy of 60 kev and a current density of 20 microamperes per cm^2 is known to reduce the optical reflectivity of glass.[1] The finite penetration of the positive ions produces a radiation damaged region whose index of refraction is intermediate between that of glass and air. The reflection coefficient will be a minimum, for a given wavelength of light, when the depth of the radiation damaged region is one quarter of a wavelength. To investigate this phenomena, a polished plate glass (composition by weight 72% SiO_2, 14% Na_2O, 12% CaO) is bombarded by an argon positive ion beam. The reflection coefficient for tungsten light fo the bombarded glass surface is measured as a function of bombardment time, ion beam current density, and ion energy. For a 33-kev argon ion beam and a current density of 100 microamperes per cm^2, the reflectivity decreases rapidly as a function of bombardment time and reaches a limiting value in approximately one minute. The limiting value of reflectivity is independent of current density from 50 to 460 microamperes per cm^2. The reflectivity decreases with increasing ion energy and passes through a minimum of 0.16 times the reflectivity of an untreated glass surface for bombardment by 42-kev argon ions.

[1] J. Koch, Nature **164**, 19 (1949).

X2. The Auger Effect in Iron, Nickel, Copper, Zinc.* CHARLES E. ROOS, *University of California, Riverside.*—The *K* fluorescence yields were measured by a scintillation counter method,[1] which utilizes the isotropic emission of fluorescent x-rays. Collimated primary x-rays passed through a sample foil and were detected by a scintillation counter. By moving the foil one could vary the solid angle subtended by the counter from 1.97π to 0.02π. This enabled one, effectively, to turn the fluorescent radiation "on" and "off." The difference between these two readings is primarily due to fluorescence. From a ratio of this difference and the direct primary beam, the *K* fluorescence yield of the sample can be determined. The following preliminary values were obtained: Fe – (0.29); Ni – (0.35); Cu – (0.39); and Zn – (0.43). The probable error is approximately 3%. Corrections were made for counter efficiency, phosphorescence of the NaI-Tl crystal and the effects of scattering, and absorption. These new values are uniformly 10% lower than the average of the earlier measurements, which all used the ionization chamber method. The new results give better agreement with theory.

* Experimental measurements were made at the Johns Hopkins University.
[1] C. E. Roos, Phys. Rev. **93**, 401 (1954).

X3. Normal Coordinate Treatments and Thermodynamic Properties of PF Cl_2 and POF Cl_2. EDWARD A. PIOTROWSKI AND JOSEPH S. ZIOMEK, *De Paul University.*—The Raman spectral data for PF Cl_2 and POF Cl_2 were collected and examined for the best available values of the wave numbers ($\Delta\sigma$), intensities (*I*) and depolarization factors (ρ). The values adopted for ($\Delta\sigma$,ρ) are as follows: for PF Cl_2: 200*P*, 327*P*, 524*P*, 827*P*, 496*D* and 271*D*; for POF Cl_2: 207(0.55), 300(0.6), 386(0.3), 547(0.05), 894(0.45), 1331*P*, 620(6/7), 372(6/7), and 254(6/7) in kaysers. No infrared data for these two substances were available. Next normal coordinate treatments (*FG* matrix method) on the basis of the most probable model (C_s) were conducted for PF Cl_2 and POF Cl_2. Here the *F* matrix elements were estimated in such a manner that the potential constants for PF Cl_2 had nearly the same values as the corresponding constants in PF_3 and P Cl_2 and for POF Cl_2 the potential constants had nearly the same values as the corresponding ones in PO Cl_3, POF_3, and PF Cl_2. Finally the above spectral data were used to calculate the values of the thermodynamic properties for these substances up to a rigid rotator harmonic oscillator approximation for temperatures from 200°K to 1000°K.

X4. Normal Coordinate Treatment for the Out-of-Plane Vibrations of Ethylene Type Molecules.* J. M. DOWLING, *Illinois Institute of Technology.*—Using the Wilson[1] *FG* matrix method the wave numbers corresponding to the out-of-plane fundamental frequencies for a number of ethylene type molecules were calculated. The *g* (inverse kinetic energy) matrix elements were calculated from the **s** vectors derived explicitly in the papers of Malhiot and Ferigle.[2] All possible second-degree terms were included in the *F* matrix describing the potential energy function. Numerical calculations were carried out for C_2H_4, asymmetric $C_2H_2F_2$, asymmetric $C_2H_2Br_2$, the *cis*- and *trans*-isomers of $C_2H_2Cl_2$, and all of their deuterated analogs. The 57 out-of-plane fundamentals were calculated for the above 19 molecules. Of these 57 fundamentals, 50 have been reported in the literature and are reproduced with an average deviation of 2.2K (cm^{-1}).

* This investigation was supported in part by grants from the Research Corporation and the National Science Foundation.
[1] E. B. Wilson, Jr., J. Chem. Phys. **7**, 1047 (1939); **9**, 76 (1941).
[2] R. J. Malhiot and S. M. Ferigle, J. Chem. Phys. **22**, 717 (1954); **23**, 30 (1955).

X5. Potential Constants for the CHDClBr, CH_2F_2, CD_2F_2, and $CHDF_2$ Molecules.* A. G. MEISTER, J. M. DOWLING, A. N. TAKATA, AND A. J. BIELECKI, *Illinois Institute of Technology.*—The potential constants for the most general quadratic potential function were calculated for these molecules using the Wilson *FG* matrix method. For CHDClBr, the potential constants were found to be the same as those used for CH_2ClBr and CD_2ClBr in previous investigations in this laboratory.[1] The agreement between the observed and calculated wave numbers of the fundamentals of CHDClBr was to within 2.5%. For CH_2F_2 the agreement was to within 1%. No comparison could be made for CD_2F_2 and $CHDF_2$ because no observed wave numbers of the fundamentals could be found in the literature.

* This investigation was supported in part by grants from the Research Corporation and the National Science Foundation.
[1] Weber, Meister, and Cleveland, J. Chem. Phys. **21**, 930 (1953).

X6. Frequencies and Relative Intensities of R_1 and R_2 Bands in KCl.* ROBERT HERMAN,† *University of Maryland,* AND M. C. WALLIS AND R. F. WALLIS, *Applied Physics Laboratory, The Johns Hopkins University.*—Measurements have been made of the intensities of the R_1 and R_2 bands in KCl as a function of duration of *F*-light irradiation. Both x-rayed and additively colored crystals were used. The x-raying and the *F*-light irradiation were done at room temperature. The optical absorption measurements were made at liquid nitrogen temperature. In both the x-rayed and additively colored samples the ratio of the R_2 and R_1

band intensities varied by less than a factor 1.5 when the individual intensities varied by a factor 6 or greater. No other pair of bands showed such a small variation in their intensity ratio. Theoretical frequencies and oscillator strengths were obtained for the $1s\sigma-2p\sigma$ and $1s\sigma-2p\pi$ transitions of H_2^+ immersed in a dielectric medium. Using the high-frequency dielectric constant of KCl, the calculated frequencies correspond to 1900 and 490 mμ, respectively; the oscillator strengths are 0.25 and 0.47. Frequencies were obtained for the $^1\Sigma_g^+-{}^1\Sigma_u^+$ and $^1\Sigma_g^+-{}^1\Pi_u$ transitions of H_2 immersed in a dielectric medium. For KCl the calculations yield 765 and 620 mμ. It appears possible that the observed R_1 and R_2 bands may arise from two transitions of the system of two electrons trapped at a pair of negative ion vacancies.

* This work supported by the Bureau of Ordnance, Department of the Navy.

† On leave from Applied Physics Laboratory, The Johns Hopkins University.

X7. Electron Loss Cross Section for Fast Helium Atoms. C. F. Barnett and P. M. Stier, *Oak Ridge National Laboratory.*—The cross section for electron loss has been determined for fast helium atoms passing through gases. The energy range studied was from 30 to 200 kev and the stopping gases investigated were hydrogen, helium, nitrogen, oxygen, neon, and argon. Helium ions from the Cockcroft-Walton accelerator were converted to fast helium atoms by charge exchange. This atomic beam entered a differentially pumped gas cell within which a transverse electrostatic field could be applied. The cross section was determined by observing the attenuation as a function of gas pressure. It will be shown that as the fast neutral atoms are formed by electron capture, it appears that an appreciable number are left in the metastable state. Subsequent collisions produce an equilibrium distribution between the ion, metastable state atom and ground-state atom components. The electron loss cross sections to be reported are for the neutral component of such an equilibrium beam. Curves will be presented showing the rapid increase in these cross sections as the velocity of the helium atom is increased. The cross sections at 200 kev are 6.0, 10.0, 19.8, 23.0, 23.0, 37.2×10^{-17} cm^2/atom for H_2, He, Ne, N_2, O_2, and A, respectively.

X8. Measurement of Electron Mobilities in Gases. Joseph C. Bowe, *Argonne National Laboratory.*—The drift velocity of electrons moving in collision equilibrium with a gas under the action of a uniform electric field is determined by measuring the time required for them to cross the gap of a parallel plate condenser. A flash tube capable of delivering intense, short duration bursts of ultraviolet light is used to release photoelectrons from the cathode. The number of photoelectrons released with each burst of light is large enough to permit the use of a transient amplifier for the amplification of the signal. The time of drift is obtained by displaying the signal on an oscilloscope. The parallel plate condenser is mounted in a metal chamber 8 inches in diameter by 4 inches and is part of a helium tight all metal system free from soldering fluxes and organic materials which might contaminate the gas. Some difficulties encountered in securing a tight, all metal system will be discussed. Data obtained in the gases studied will also be presented.

X9. Electroluminescence in Zinc Sulfide. W. A. Thornton, *General Electric Research Laboratory.*—A simple theory, based upon a single-level trapping and field-release process, predicts detailed dependences of electro-luminescence light output wave form and integrated light output on voltage, frequency, and temperature. Extensive data, obtained with the use of zinc sulfide phosphor powder layers, are in qualitative or quantitative agreement with the theory. Negligible frequency dependence of integrated light output at low fields and low temperatures is predicted and experimentally confirmed. Small temperature dependence, over a wide range of temperatures, at high fields and low frequencies and strong temperature dependence at low fields and high frequencies is predicted and observed; this latter effect is an explanation for both strong and weak temperature dependences being reported in the literature. A proposed sequence of processes throughout the voltage cycle is based upon the theory plus supplemental data involving glow curves, photoluminescence, and spectral content of the electroluminescence emission.

Saturday Afternoon at 1:45

Oriental 104

(R. H. Crane presiding)

The Brookhaven Electron Analog

Y1. The Electron Analog.* G. K. Green, E. D. Courant, L. J. Haworth, and H. S. Snyder, *Brookhaven National Laboratory.*—An electron accelerator has been constructed to test in detail the particle orbits of a strong-focusing, or alternating-gradient, synchrotron. This electron accelerator is not a model of any specific large synchrotron, but is rather an analog of the general alternating-gradient focusing system. The orbit of this machine is 45 feet in diameter and the aperture 0.8 inch square. Electrons are injected from a small Van de Graaff at 1 Mev and can be accelerated by a single rf cavity to a maximum energy of 10 Mev. Guide and focusing fields are electrostatic. 160 hyperbolic lenses make up the basic alternating-gradient field which can be modified linearly by electrostatic quadrupoles, and nonlinearly by sextupoles and octupoles. The machine is designed to explore all classes of resonances over at least one full diamond of the stability diagram, and to pass through the phase transition at about the geometric mean of its energy range.

* Work carried out under contract with U. S. Atomic Energy Commission.

Y2. Electron Analog—Construction.* D. D. Jacobus, C. L. Gould, J. J. Grisoli, and I. J. Polk, *Brookhaven National Laboratory.*—The lenses of the electron analog are fabricated of Type 303 stainless steel. Hyperbolic surfaces were machined with formed milling cutters. The electrodes were spaced in aluminum frames with accurately ground ceramic insulators. Five sets of paired bending lenses, one quadrupole lens, one sextupole lens, one octupole lens, and one set of pickup electrodes are pinned in true relative positions to an aluminum box girder. Sixteen of these box girder assemblies were placed on a true circle by the use of a radius bar and micrometer gauge, with concrete piers as supports. The surrounding

vacuum chamber is farbicated of ferritic stainless steel, and is independently supported through expansion joints. The radial and vertical positions of the aperture, and all other critical dimensions, were calibrated on each assembled bending lens. The average deviation was of the order of ±0.002 in. Sixteen ten inch mercury diffusion pumps, each with cold wall type of liquid nitrogen trap and freon baffle, produce a pressure of 5 to 6×10^{-7} mm of Hg in the system. Convaseal is used as the gasket material. Refrigerated baffles prevent oil migration from a Kinney forepump to the mercury pumps. The entire system uses about 20 liters per hour of liquid nitrogen.

* Work carried out under contract with U. S. Atomic Energy Commission.

Y3. Electron Analog—Electrical System.* J. G. COTTINGHAM, N. C. CHRISTOFILOS, M. PLOTKIN, E. C. RAKA, AND R. H. RHÉAUME, *Brookhaven National Laboratory.*—Electrical equipment for the electron analog required the solution of several unusual circuit problems. The 20 kv inflector potential must be removed precisely within a fraction of the revolution period (140 millimicroseconds) to allow the passage of the beam through the inflector on the second and successive revolutions. The potential difference on the guide field electrodes is increased linearly to 60 kv in 5 milliseconds, balanced with respect to ground. The system of electrostatic field-correction lenses can be energized either with linearly rising potentials, or with numerous combinations of steady potentials. Beam position, intensity, and revolution frequency are sensed by pickup electrodes and their associated amplifiers. Frequency information from the pickup electrodes is processed through an electronic phase correction circuit and feeds a power amplifier which applies the rf potential to the accelerating gap of the ferrite-loaded cavity. Electronic means for crossing the phase transition have been designed.

* Work carried out under contract with U. S. Atomic Energy Commission.

Y4. Electron Analog—Initial Setup.* J. SPIRO, J. G. COTTINGHAM, E. E. COURANT, AND R. R. KASSNER, *Brookhaven National Laboratory.*—To prevent the accumulation of tolerances in the stacking of lenses, and the resultant perturbation on the electron beam, a specified arrangement was devised. The gauge measurements of individual lens assemblies were reduced to equivalent horizontal and vertical displacements of the electrical field. The lenses were then sequenced so that low order azimuthal harmonics of the horizontal deviation were minimized. The corresponding vertical deviations were then in random order. Computations indicate that the resulting equilibrium orbit excursion is 0.03 inch radially, ($\frac{1}{4}$ the extreme variation between lenses), and 0.07 inch vertically (twice the extreme between lenses). Measurements taken around the electron orbit after preliminary degaussing showed a residual magnetic field varying up to one gauss. Some of the techniques used to reduce these fields to 20 milligauss will be presented. Focusing, steering, and observation of the injected beam are accomplished along the pipe connecting the Van de Graaff to the inflector tank. The timing system of the electron analog is synchronized with the 60-cycle line frequency. Stray magnetic fields from an unsynchronized alternator near the Van de Graaff electron source produced an undesirable beat in the injected beam. A synchronizer reduced the beat, and careful adjustment of the injection system reduced the jitter.

* Work done under contract with U. S. Atomic Energy Commission.

Y5. Electron Analog—Performance and Interpretation. I.* *E. C. RAKA, E. D. COURANT, R. R. KASSNER, L. J. LASLETT,† H. S. SNYDER, AND J. SPIRO, *Brookhaven National Laboratory.*—The injected beam is allowed to circulate in a static guide field permitting an investigation of the nature of the equilibrium orbit. Various configurations of correction fields are applied and their effects on the betatron oscillations, usable aperture, and resonance bands are studied. Observation of the beam is accomplished both by visual and electrical methods. From oscilloscope patterns it is possible to identify the class of resonance excited, although not the order. Application of the rf accelerating voltage has been carried out successfully, and preliminary results under dynamic operating conditions will be described.

* Work carried out under contract with U. S. Atomic Energy Commission.
† On summer leave from Iowa State College.

Y6. Electron Analog—Performance and Interpretation. II.* E. D. COURANT, R. R. KASSNER, E. C. RAKA, LLOYD SMITH,† AND J. SPIRO, *Brookhaven National Laboratory.*—The quadrupole correcting lenses in the electron analog can be adjusted so as to change the frequencies ν_x and ν_y of the horizontal and vertical betatron oscillation. According to the linear theory resonances should make the beam unstable if ν_x or ν_y are integral or half-integral, or if $\nu_x+\nu_y$ is integral. The integral resonances always lead to complete loss of the beam over a range of about 100 volts of quadrupole voltage. This range can be narrowed by appropriate settings of "kicker" electrodes. The half-integral and sum resonances sometimes lead to complete loss of beam in narrow bands; sometimes the beam survives. If the quadratic component of the focusing field contains azimuthal Fourier harmonics of the order 3ν (produced with kickers or sextupoles) there is also loss when ν is $\frac{1}{3}$ integral or if $2\nu_x+\nu_y$ is integral. Partial losses at $\nu=\frac{1}{4}$ integer can be induced by azimuthal variations in the cubic field. These nonlinear resonances can also be explained by theory. When the quadrupole voltages are varied with time so as to run through resonances, the beam is generally lost if and only if the corresponding resonance causes loss under static conditions.

* Work carried out under contract with U. S. Atomic Energy Commission.
† On leave from University of California.

SUPPLEMENTARY PROGRAMME

SP1. $Sr^{86,87,88}$, Y^{89}, Zr^{92} (γ,n) Cross Sections. PAUL F. YERGIN AND BURTON P. FABRICAND, *University of Pennsylvania.**—We have measured these cross sections from threshold to 23 Mev. All show the usual giant resonance, at about 16 Mev. The width of the resonances show systematic variation not attributable to $(\gamma,2n)$ or (γ,pn) contributions. They provide further evidence of the effect of the magic neutron number, 50, on the giant resonance width. The lesser widths are not associated with greater heights; instead the integrated cross section decreases substantially when the peak becomes narrower. We also observe that the rise of the cross section into the peak, from 12.5 to 15.5 Mev, is almost exactly the same in shape and magnitude for all 5 isotopes, as well as for the previously measured[1] Zr^{90} and Zr^{91}. In agreement with the conjecture of Wapstra[2] we find the $Sr^{86}(\gamma,n)$ threshold to be at about 11.5 Mev, not at 9.5 Mev as previously reported.

* To be given at the end of Session I if the chairman rules that time permits.
[1] R. Nathans and P. F. Yergin, Phys. Rev. **98**, 1296 (1955).
[2] A. H. Wapstra, Physica **21**, 385 (1955).

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